CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

REGIONAL WATER QUALITY CONTROL BOARD
CENTRAL VALLEY REGION

Sulphur Creek TMDL for Mercury

Final Staff Report

May 2006

11020 Sun Center Drive #200
Rancho Cordova, California 95670-6114

Phone: (916) 464-3291

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REPORT PREPARED BY:

STACY STANISH
Environmental Scientist

And

JANIS COOKE
Environmental Scientist

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SULPHUR CREEK MERCURY TMDL

EXECUTIVE SUMMARY

The Central Valley Regional Water Quality Control Board has determined that Sulphur Creek (Colusa County) is impaired due to elevated levels of mercury. Because of this impairment, Regional Board staff has prepared a Total Maximum Daily Load (TMDL) water quality management strategy. The Sulphur Creek TMDL includes: water quality numeric targets, assessment of pollutant sources, linkage between the numeric target and loads, assignment of load reductions, a margin of safety, and a preliminary implementation plan. The goal of this TMDL is to lower mercury and methylmercury levels in Sulphur Creek such that beneficial uses are protected and loads of mercury entering Bear Creek are reduced. The TMDL encompasses the seven-mile reach between the headwaters of Sulphur Creek to its confluence with Bear Creek.

Mercury Sources

Sources of mercury entering the watershed include waste rock, ore and tailings from historic mercury mines, geothermal springs, erosion of mineralized and non-mineralized (background) soil, and atmospheric deposition. There are six inactive mines in the lower Sulphur Creek watershed and at least two inactive mines in the upper watershed that contribute mercury to the creek. The streambed and banks are contaminated with mine tailings and waste rock, which contribute mercury to the creek as they erode. Multiple geothermal springs discharge to the creek, including some within the creek bed.

Mercury is transformed to methylmercury in sediment by sulfate-reducing bacteria. Sources of methylmercury include in-channel production, direct geothermal discharge, and drainage from the interaction of geothermal water with mine wastes.

Sulphur Creek was sampled during winter storms and non-storm events between 1998 and 2004. At the flow gauge near the confluence with Bear Creek, total mercury concentrations (unfiltered) ranged between 245 and 16,411 ng/L, with an average of 2890 ng/L. Methylmercury concentrations (unfiltered) at the gauge averaged 3 ng/L with a range of 0.06 to 20 ng/L. Average, annual loads of total mercury and methylmercury were 7-12 kg/year and 7 g/year, respectively. Most mercury in Sulphur Creek is transported during storms and associated runoff. The years of study are not classified as “wet” years. Larger or more frequent storm events could remobilize and transport even larger mercury loads. On an average annual basis, Sulphur Creek contributed 48% of the mercury and 41% of the methylmercury loads to Bear Creek.

Concentrations of mercury and suspended solids were sampled at multiple sites in the watershed on six occasions. These data were used to develop load estimates for tributaries and sub-watersheds of Sulphur Creek. Tributaries associated with mines (Clyde, Elgin, Empire and Wide Awake Mines) contribute 44% of the mercury loads measured at the gauge. The upper watershed provides about 10% of the loads, which are from contaminated in-stream sediment, erosion of background soil, and unidentified geothermal springs. Mercury loads in the mainstem of Sulphur Creek between West End mine and the USGS gauge account for 56% of the total mercury loads. Sources in this area include geothermal springs, contaminated stream sediment, and erosion from mines.

Numeric Targets for Mercury

This TMDL proposes a numeric target for mercury in sediment based on natural or background concentrations. This target should protect all wildlife, aquatic life, stock watering and human contact and non-contact recreational beneficial uses of Sulphur Creek. Large fish have not been observed in the creek, suggesting that humans and large wildlife species (bald eagle, osprey, otter) are not exposed to methylmercury through consumption of fish.

The background sediment target is applicable to areas of the watershed that are not within the mineralized zones and is termed the regional background. Mineralized zones are enriched in mercury by geologic processes and include the geothermal springs or mining areas. The proposed regional background target is 0.2 mg/kg dry weight in fine-grained sediment.

Regional Board staff is proposing a preliminary cleanup goal for mercury in soil transported off of the Sulphur Creek mine areas of 3 mg/kg, which is approximately double the concentration found at the periphery of the mercury mineralized zone around the Cherry Hill and Manzanita mines. This preliminary cleanup goal should be refined when soil data are gathered for each mine site.

Linkage Analysis

Methylmercury production is controlled by multiple factors, with the primary factor being inorganic mercury concentrations in sediment. Studies conducted in the Cache Creek watershed and elsewhere have shown statistically significant relationships between methyl and total mercury, where methylmercury in sediment is a function of its total mercury content. This pattern is also seen in Sulphur Creek. Total mercury loads enter Sulphur Creek, which result in increased instream methylmercury production. As a consequence, Sulphur Creek exports considerable loads of mercury and methylmercury to Bear Creek. Reducing total mercury loads from identified sources will lead to reduced methylmercury loads in Sulphur and Bear creeks.

Load Allocations and Preliminary Implementation Plan

This TMDL identifies the reduction in total mercury loads needed to eliminate inputs related to mining and other anthropogenic activities and restore the watershed to its estimated pre-mining conditions. Geothermal spring inputs and erosion of soil undisturbed by mining are generally considered to comprise the natural or background loads of mercury in Sulphur Creek. Inactive mine sites themselves are assigned a specific allocation of no more than 5% of existing mine-related loads entering the creek from each site.

Table ES.1 Sulphur Creek Total Mercury Budget by Source Type and Load Allocations

Source	Current Load, kg/yr (a)	**Load Allocation** as percent of existing loads (b)	Future Load, based on current load estimates, kg/yr
Geothermal springs	1.4	100%	1.4
Non-mine site erosion	1.2	60%	0.5
Clyde Mine	0.4	5%	0.02
Elgin Mine	2.7	5%	0.13
Wide Awake Mine	0.8	5%	0.04
Lower Watershed Mines plus contaminated stream bed	5.3	15%	0.8
Atmospheric Deposition	0.03	100%	0.03
Sum	11.8	25%	2.9

(a) Based on estimates from data collected in 2000-2004.
(b) Load allocations are expressed as a percentage of existing loads. For average water years, a comparison between current and future loads is given.

The goals of the implementation plan will be to reduce the mercury concentration in sediment within Sulphur Creek and to reduce the overall loading of mercury and methylmercury to Bear Creek. To achieve these goals, staff will propose a program that could include these major components:

1) Reduce total mercury discharges from the mercury mine sites;
2) Reduce the concentration of mercury in Sulphur Creek sediment adjacent to and downstream of the mercury mines;
3) Control erosion of contaminated sediments within the Sulphur Creek watershed where the total mercury sediment concentrations are greater than 0.2 mg/kg, dry weight; and
4) Evaluate the feasibility of controlling mercury loads from geothermal springs.

Basin Planning

The Sulphur Creek TMDL will be enacted when amended into the Water Quality Control Plan for the Central Valley Region (Basin Plan). The Regional Board will consider adoption of amendments to the Basin Plan after a public review process. Basin Planning for the Sulphur Creek TMDL will occur in two parts. The first part will be adoption of an amendment including an implementation plan to control mercury in Sulphur Creek. The second part will be adoption of an amendment establishing site-specific water quality objectives for mercury in Sulphur Creek. The proposed Basin Plan amendment will include an implementation plan for reductions of loads of methylmercury and total mercury. Regional Board staff anticipates proposing a Basin Plan amendment to the Regional Board by June 2005.

Bas*in Planning Part 1*. Mercury reduction in the Sulphur Creek TMDL was combined with mercury strategies for Cache Creek, Harley Gulch and Bear Creek in a single Basin Plan Amendment Staff Report that included load allocations and an implementation plan for all four water bodies. The Cache Creek Watershed Mercury Basin Plan Amendment was adopted by the Central Valley Water Board on 21 October 2005. Documents related to the Basin Planning process can be viewed on the Regional Board's website, http://www.waterboards.ca.gov/centralvalley/programs/tmdl/Cache-SulphurCreek/index.html.

Basin Planning Part 2. Naturally occurring concentrations of mercury in Sulphur Creek may prevent attainment of human health criteria for drinking water. Staff may propose to modify the beneficial uses of Sulphur Creek and set site-specific water quality objectives based on background levels. Designation of the beneficial uses of Sulphur Creek could occur in a later Basin Plan Amendment process. Regional Board staff may propose that Sulphur Creek be designated for basic aquatic life, wildlife habitat, human contact and non-contact recreation and stock watering uses, but not for municipal and domestic supply or anadromous fish spawning.

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303(d) List	Clean Water Act 303(d) List of Impaired Water Bodies
Basin Plan	Water Quality Control Plan for the Central Valley Region
BMP	Best Management Practices
CTR	California Toxics Rule
CWA	Federal Clean Water Act
DFG	California Department of Fish and Game
DTMC	Delta Tributaries Mercury Council
Hg	Mercury
Hg/TSS	Mercury to total suspended solids ratio
MeHg	Methylmercury
mg/kg	Milligrams/kilogram
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
Regional Board	Central Valley Regional Water Quality Control Board
SBMM	Sulphur Bank Mercury Mine
State Board	State Water Resources Control Board
THg	Total Mercury
TMDL	Total Maximum Daily Load
TMDL Report	Sulphur Creek TMDL for Mercury
UC Davis	University of California-Davis
USBLM	U.S. Bureau of Land Management
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

1 PROBLEM STATEMENT

1.1 Introduction

The Central Valley Regional Water Quality Control Board (Regional Board) has determined that Sulphur Creek (Colusa County) is impaired by mercury. Water column concentrations in Sulphur Creek exceed the California Toxics Rule water quality mercury criterion. In addition, stream macroinvertebrates have elevated mercury levels. Sulphur Creek is on the Federal 303(d) list of impaired water bodies. The Federal Clean Water Act (CWA) requires states to identify impaired water bodies and to develop programs to correct the impairments through the Total Maximum Daily Load (TMDL) program. This report describes the TMDL for Sulphur Creek.

1.2 Regulatory Background

1.2.1 Clean Water Act 303(d) Listing and Total Maximum Daily Load Development

Section 303(d) of the Federal Clean Water Act requires states to:

1. Identify those waters not attaining water quality standards (referred to as the "303(d) list").
2. Set priorities for addressing the identified pollution problems.
3. Establish a "Total Maximum Daily Load" for each identified water body and pollutant to attain water quality standards.

The 303(d) list for the Central Valley is prepared by the Regional Board and approved by the State Water Resources Control Board (State Board) and the United States Environmental Protection Agency (USEPA). Water bodies on the 303(d) list do not meet water quality objectives even if dischargers of point sources comply with their current discharge permit requirements.

A TMDL represents the maximum load (usually expressed as a rate, such as grams methylmercury per year) of a pollutant that a water body can assimilate and not result in impairments. A TMDL describes the reductions needed to meet water quality objectives and allocates those reductions among the sources in the watershed. In order to meet state and Federal requirements, TMDLs include the following elements: description of the problem (Section 1), analysis of current loads (Section 2), numerical water quality target (Section 3), analysis of the linkage between mercury levels and targets (Section 4), load reductions needed to eliminate impairments (Section 5), margin of safety and seasonal variation (Section 6), preliminary plan of implementation to achieve the needed load reductions (Section 7), and a public participation record (Section 8).

1.2.2 Porter-Cologne Basin Plan Amendment Process and Time Schedule

The Porter-Cologne Water Quality Control Act (Section 13240) requires that the Central Valley Water Board develop a water quality management strategy for each water body and pollutant in the Central Valley that is not meeting its beneficial uses. The water quality management strategy for Sulphur Creek will include elements of the Sulphur Creek TMDL and an implementation plan. The Sulphur Creek TMDL will be enacted when amended into the Water Quality Control Plan for the Central Valley Region (Basin Plan). The Basin Plan is a legal document adopted by the Regional Board that describes beneficial uses of waters, water quality objectives to protect those uses, and a program of implementation needed for achieving the objectives (CVRWQCB, 1998). The water quality management strategy for Sulphur Creek will include several phases:

> <u>TMDL Development</u> involves the technical analysis of the sources of pollutant, the fate and transport of those pollutants, the numeric target(s), and the amount of pollutant reduction that is necessary to attain the target. (August 2004)
>
> <u>Basin Planning</u> focuses on the development of a Basin Plan amendment with Functionally Equivalent Document for consideration by the Central Valley Water Board. The Functionally Equivalent Document includes information and analyses required to comply with the California Environmental Quality Act. Development of the implementation options involves evaluation of remediation and best management practices, the identification of potentially responsible parties and possible implementation framework (e.g., waste discharge requirements), a time schedule, and a consideration of cost.
>
> Basin Planning for mercury in Sulphur Creek is occurring in two steps. The Basin Plan Amendment for mercury in the Cache Creek watershed included an implementation plan to reduce mercury and methylmercury loads in Sulphur Creek. This amendment was adopted by the Central Valley Water Board in October 2005. Because load reduction strategies for Sulphur Creek are similar to those needed in other parts of the Cache Creek watershed, it was efficient to include load allocations and the implementation plan for Sulphur Creek in the Basin Plan Amendment for the Cache Creek watershed. Specific to Sulphur Creek, though, will be adoption of water quality objectives that reflect natural background levels of mercury (contributed by thermal springs and undisturbed soil) creek. Water quality objectives for Sulphur Creek will be developed in a second amendment and environmental analysis. Staff anticipates proposing the second Basin Plan amendment for water quality objectives to the Central Valley Water Board in Fall 2006.)
>
> <u>Implementation</u> focuses on the performance of the cleanup activities and other actions as described in the implementation plan to achieve the TMDL targets. Guidance for implementation practices is provided by the Porter Cologne Water Quality Act (§13241 and §13242) and the Federal TMDL requirements (CWA Section 303(d)).

The Basin Plan amendment is legally applicable once it has been adopted by the Regional and State Water Boards and approved by the State Office of Administrative Law and the USEPA. Regional Board staff will seek public input throughout the TMDL Development and Basin Planning phases. The Basin Plan amendment will be adopted under a structured process involving public participation and state environmental review. As Regional Board staff prepares the proposed Basin Plan amendment, formal public workshops and hearings will be held.

1.3 Units and Terms Used in this Report

In this document, aqueous concentrations of mercury and methylmercury are reported in units of nanograms per liter (ng/L). Concentrations of suspended sediment are analyzed as total suspended solids (TSS) and use units of milligrams per liter (mg/L). The concentration of mercury in suspended sediment is the ratio of concentrations of mercury to suspended sediments (Hg/TSS) and is reported as mg/kg. Units for the concentration of mercury in suspended sediment and soil are ng/mg or mg/kg on a dry weight basis.

The units for loads of methylmercury and mercury are grams per year (gm/yr) and kilograms per year (kg/yr), respectively. Sediment loads are given in terms of millions of kilograms per year (kg/yr x 10^6). Water flow is presented in units of acre-feet per year for annual rates and cubic feet per second (cfs) for instantaneous flow measurements. Mine waste pile and sediment volumes are expressed in cubic yards (cy).

1.4 TMDL Scope and Watershed Characteristics

Sulphur Creek drains a 6543-acre watershed within the Cache Creek watershed, in the Coast Range of California (Figure 1). The scope of the TMDL encompasses the seven-mile reach from the headwaters of Sulphur Creek to its confluence with Bear Creek, approximately twelve miles upstream from the Bear Creek-Cache Creek confluence (SWRCB, 1999; USGS, 1991).

Sulphur Creek is an intermittent stream with continuous flows between the fall and spring months (October through June). Stretches of the stream are wet throughout the year because of inputs from springs. Watershed land use is predominantly rangeland in undeveloped chaparral and California scrub oak (Foe and Croyle, 1998).

The nearest rain gauge to Sulphur Creek is at the Indian Valley Reservoir. Precipitation at the reservoir between the 1996 and 2001 water years typically averaged 25 inches per year; however, precipitation exceeded 45 inches in an above-average wet year. The majority of rain typically falls between November and March. During the winter, snow occasionally falls in the mountains above the 3,000-foot elevation. Mean annual temperatures for the region are approximately 62 degrees Fahrenheit (^{o}F), with summer temperatures exceeding 100^{o}F and winter temperatures dropping below freezing.

The U.S. Geological Survey (USGS) has mapped numerous springs discharging in the area (Barnes *et al*., 1975). A shallow magma chamber beneath the Geysers-Clear Lake area is the source of geothermal activity and springs in the Sulphur Creek watershed. Several thrust faults underlie the watershed (Pearcy and Petersen, 1990). Identifiable geothermal springs discharging to Sulphur Creek include the Jones Fountain of Life (Jones Fountain), Blanck Springs, Elbow Springs, Elgin Spring, and the Wilbur Hot Springs. Jones Fountain is a geysering spring near the edge of Sulphur Creek that erupts approximately every twenty minutes. The Wilbur Hot Spring system, also located near the edge of Sulphur Creek, supports a commercial resort and spa. Wilbur Hot Spring water is piped by gravity flow through the resort baths and a pool.

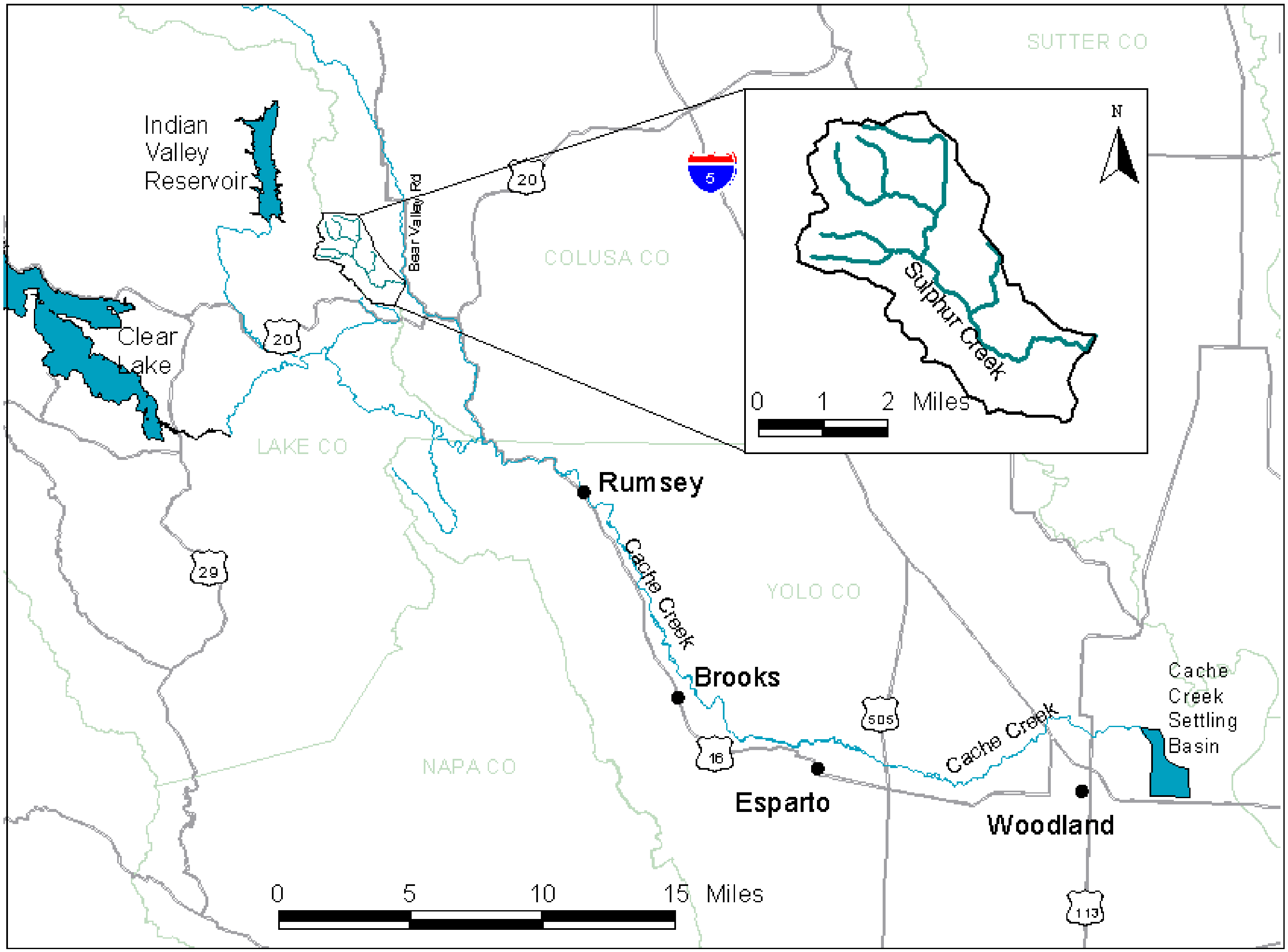

Figure 1.1 Cache Creek Watershed

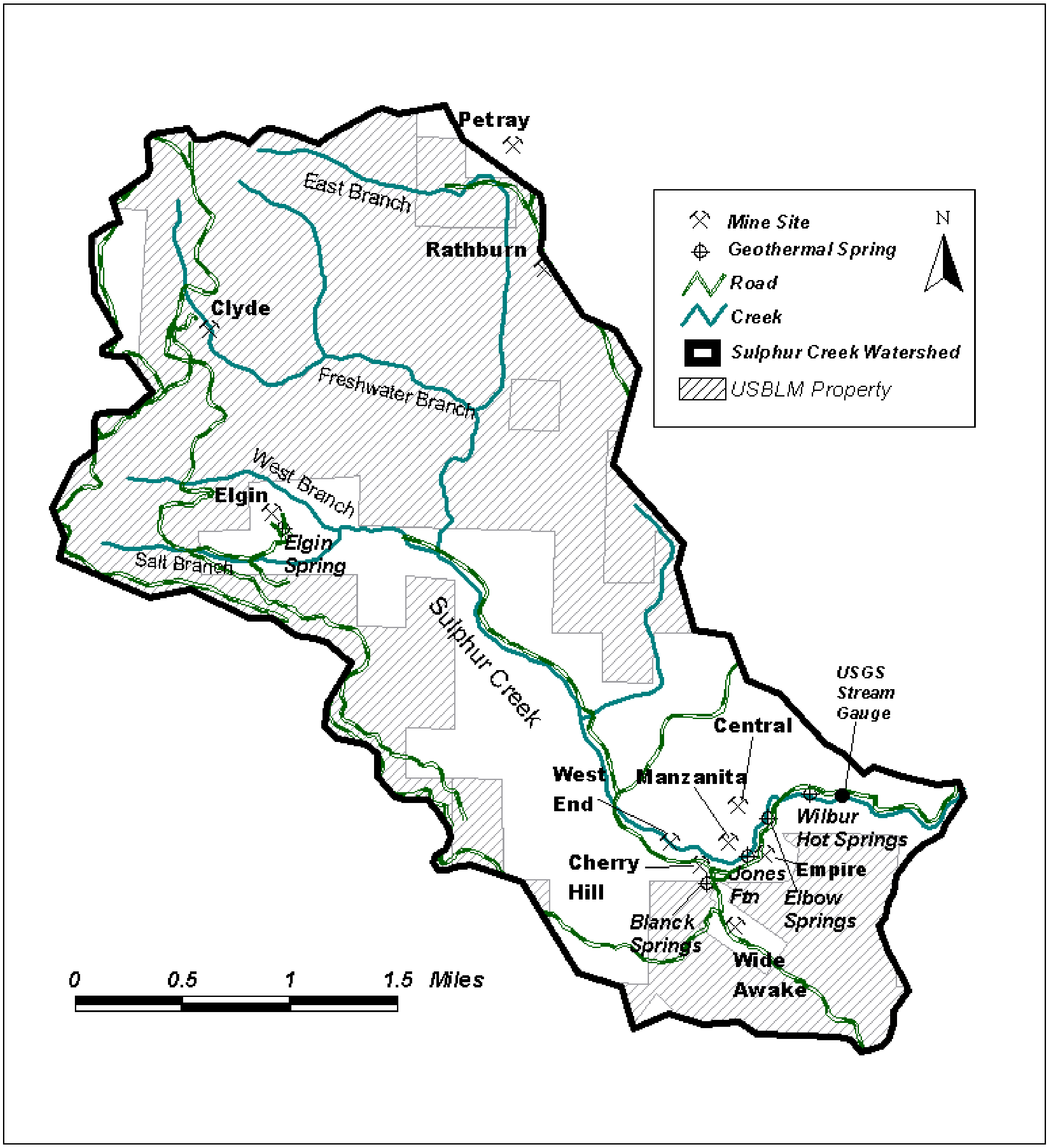

Figure 1.2 Sulphur Creek Watershed

Part of the Sulphur Creek watershed area is privately owned. The U.S. Bureau of Land Management (USBLM) administers land in the upper portion of the watershed. Cattle graze on some private property in the lower watershed. The Wilbur Hot Springs resort is the year-round home to about seven people. There are no other year-round residences in the watershed.

1.5 Mercury Sources in the Sulphur Creek Watershed

The Sulphur Creek watershed lies within region naturally enriched in mercury. The volcanism and faulting in the area produced mercury, gold and sulfur deposits that were mined at various periods between 1860 and 1970. Sources of mercury entering Sulphur Creek include excavated overburden, ore and tailings from historic mining operations; erosion of naturally mercury-enriched soils in the mineralized zone; geothermal springs; erosion of soil with background levels of mercury; runoff and emissions from historic mine facilities, and atmospheric deposition. The Sulphur Creek mining district includes six inactive mines (Central, Empire, Wide Awake, Cherry Hill, West End, and Manzanita) in the lower watershed and six inactive (Clyde, Elgin, Rathburn, Rathburn-Petray, South Petray, and North Petray) mines in the upper watershed.

Sulphur Creek contributes significant amounts of mercury to Bear Creek. During three storm flow events between January 1997 and February 1998, Regional Board staff collected water samples from the mouth of Sulphur Creek and from locations up and downstream of the tributary input to ascertain whether the tributary enhanced or diluted mercury concentrations in Bear Creek (Foe and Croyle, 1998). During two surveys, mercury concentrations in Sulphur Creek increased downstream concentrations in Bear Creek four to six fold. The source analysis prepared for the Bear Creek TMDL showed that, on an average annual basis, Sulphur Creek contributed 48% of the mercury and 41% of the methylmercury loads to Bear Creek (CVRWQCB, 2004).

1.6 Toxicity of Mercury

1.6.1 Mercury Accumulation in Biota

Both inorganic mercury and organic mercury can be taken up from water, sediments, and food by aquatic organisms (Figure 1.3). Because organic mercury uptake rates are generally much greater than rates of elimination, methylmercury concentrates within organisms. Low trophic level species such as phytoplankton obtain most mercury directly from the water. Piscivorous (fish-eating) fish and birds obtain most mercury from contaminated prey rather than directly from the water (USEPA, 1997).

Repeated consumption and accumulation of mercury from contaminated food sources results in tissue concentrations of mercury that are higher in each successive level of the food chain. The proportion of total mercury that exists as the methylated form generally increases with level of the food chain (Nichols *et al.*, 1999). This occurs because inorganic mercury is less well absorbed and/or more readily eliminated than methylmercury.

1.6.2 Human Health

Mercury is a potent neurotoxicant, with methylmercury being the most toxic form. Ingestion of large amounts of methylmercury has resulted in impaired central nervous system function, kidney and gastrointestinal damage, cardiovascular collapse, shock, and death. Effects from lower ingestion rates included impairments to peripheral vision, speech, hearing, and walking. Adverse neurological effects in children appear at dose levels five to ten times lower than dose levels associated with toxicity in adults (NRC, 2000).

Effects of methylmercury are dependent upon the dose received. The aquatic food web provides more than 95% of humans' intake of methylmercury (USEPA, 1997). There is no evidence of acute or chronic methylmercury toxicity to humans due to consumption of organisms from Sulphur Creek or Bear Creek. Exposure studies, however, have not been conducted.

1.6.3 Wildlife Health

Wildlife species may also experience detrimental effects from methylmercury exposure. The greatest concern for toxicity is for wildlife species that consume fish or other aquatic organisms. Adverse effects that have been observed with multiple species in the field or laboratory include impaired learning, ineffective social behaviors, weakened physical abilities, neurological damage, and reproductive impairment (Wolfe *et al.*, 1998). There have been no studies conducted to date showing adverse effects of methylmercury on wildlife species in the Sulphur Creek watershed.

1.7 Beneficial Uses and Applicable Standards

1.7.1 Beneficial Uses

The Federal Clean Water Act and the State Water Code (Porter-Cologne Water Quality Act) require identification and protection of beneficial uses. The Basin Plan identifies the designated existing and potential beneficial uses of surface waters in the Sacramento and San Joaquin Basins (CVRWQCB, 1998, Figure II-1 and Table II-1). Beneficial uses for Sulphur Creek are not explicitly assigned in the Basin Plan; however, the Basin Plan states that the beneficial uses of any specifically identified water body generally apply to its tributary streams. Sulphur Creek is a tributary to Bear Creek, which is a tributary to Cache Creek. Table 1.1 lists the beneficial uses of Cache Creek, which may be applied to Sulphur Creek by the Regional Board. Under the Sources of Drinking Water Policy (State Water Resources Control Board Resolution 88-63), the municipal and domestic supply designation (MUN) applies to this water body.

The major beneficial use of Sulphur Creek that is currently unmet due to mercury is as a safe habitat for wildlife species consuming organisms from the creek. Existing mercury levels also do not support the municipal and domestic supply (MUN) use.

Table 1.1 Existing and Potential Beneficial Uses of Cache Creek

Beneficial Use (CVRWQCB, 1998) (a)	Status
Municipal and domestic supply (MUN)	Existing [(b)]
Agriculture – irrigation and stock watering (AGR)	Existing
Industry – process (PROC) and service supply (IND)	Existing
Recreation – contact, canoeing, and rafting (REC-1)	Existing
Other non-contact (REC-2)	Existing
Freshwater habitat (Warm)	Existing
Freshwater habitat (Cold)	Potential
Spawning (SPWN) – warm and cold	Existing
Wildlife habitat (WILD)	Existing [(b)]

(a) The Basin Plan lists these uses for Cache Creek. They may be applied by the Regional Board to Sulphur Creek.
(a) Beneficial uses impaired by mercury in Sulphur Creek

1.7.2 Water Quality Objectives

The Numeric Target Section discusses development of a numeric target based on natural background levels on mercury in the Sulphur Creek watershed. Other water quality criteria that apply to Sulphur Creek are discussed below. There are several different goals for aqueous concentrations of inorganic (total recoverable) mercury and one for methylmercury. A natural background target is more stringent in terms of protecting current aquatic life, wildlife, and humans beneficial uses than the water quality criteria described below.

Fish Tissue Goals

The USEPA recently published a recommended criterion for the protection of human health of 0.3 mg/kg methylmercury in the edible portions of fish (USEPA, 2001). This goal can be compared with the single fish sample described below. The Cache and Bear Creek TMDLs focused on water quality goals for methylmercury in fish as being most protective of beneficial uses where fish are consumed. In a recent electroshocking event; however, the California Department of Fish and Game (DFG) found no fish in Sulphur Creek. As will be described, Regional Board staff proposes an alternative type of target for Sulphur Creek.

Aqueous Criteria and Goals

The USEPA has issued a safe level of methylmercury in drinking water to protect humans of 70 ng/L (Marshack, 2003). This level is obtained through USEPA's Integrated Risk Information System and is based on USEPA's current reference dose of methylmercury. The maximum methylmercury concentration recorded in Sulphur Creek was 20 ng/L (Slotton *et al*, 2004a). The USEPA drinking water level is not expected to be exceeded in Sulphur Creek.

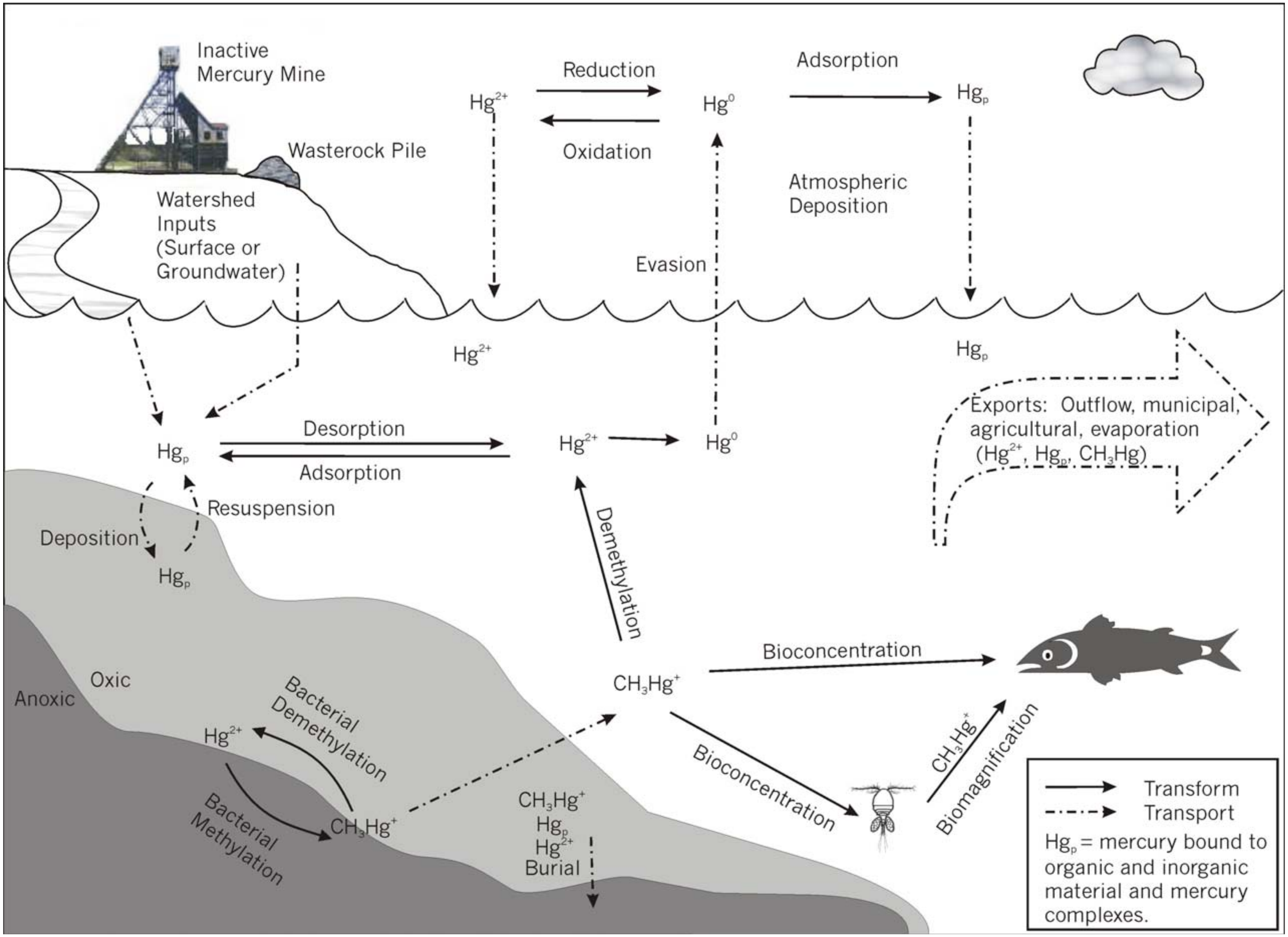

Figure 1.3 Mercury Cycling Conceptual Model

Although not issued specifically for California waters, a guidance level to protect the drinking water for livestock of 10,000 ng/L total mercury was developed by the United Nations (Ayers and Westcot, 1985). Livestock and wildlife species use Sulphur Creek for drinking water. The guidance level is exceeded in water taken directly from Jones Fountain and other geothermal springs. The geothermal waters are diluted as they enter Sulphur Creek. Water in Sulphur Creek occasionally exceeds the livestock guidance level during storm-related flows (Table 1.2).

The USEPA promulgated the California Toxic Rule (CTR) in April 2000 (USEPA, 2000). The CTR contains a water quality criterion of 50 ng/L total recoverable mercury for freshwater sources of drinking water.[1] The CTR criterion protects humans from exposure to mercury in drinking water and contaminated fish. The CTR criterion is enforceable for all waters with a municipal and domestic water supply beneficial use designation.

The CTR is likely exceeded during the winter in Sulphur Creek, especially during high water years. The CTR should be compared with averages of aqueous concentrations of total recoverable mercury occurring over 30-day periods. Continuous data have not been collected in Sulphur Creek. Regression analysis of flow and mercury concentration at the Sulphur Creek gauge indicate that 30-day average concentrations of mercury in Sulphur Creek were greater than 50 ng/L for several 30-day periods in a single winter.

1.8 Available Monitoring Data

Water samples have been collected at the USGS gauge near the creek mouth. Sediment at mine sites and water samples have been collected through research supported by the California Bay-Delta Authority (Churchill and Clinkenbeard, 2004; Suchanek *et al.*, 2004). Regional Board staff worked with California Department of Fish and Game (DFG) at Moss Landing to gather additional data in 2002-2004.

1.8.1 Fish Tissue Data

In December 2000, UC Davis researchers collected tissue samples from approximately 200 fish at diverse locations in the Cache Creek watershed as part of the CALFED mercury grant (Slotton *et al*., 2004a). One fish was collected upstream from the mouth in Sulphur Creek. The sample was a single California roach, *Lavinia symmetricus*, with a mercury concentration of 0.34 mg/kg, wet weight. In a survey conducted by electroshocking in April 2004, no fish were found in Sulphur Creek between Jones Fountain and the creek mouth (DFG, 2004).

[1] The Federal rule did not specify duration or frequency terms. However, Regional Board staff has previously employed a 30-day averaging interval with an allowable exceedance frequency of once every three years for protection of human health, which is recommended for application of this criterion (Personal communication from P. Woods, USEPA Region 9 to J. Marshack, CVRWQCB, 12/04/01).

1.8.2 Water Data

Several studies have collected water samples throughout Sulphur Creek and its tributaries. Regional Board staff and Suchanek and colleagues (2004) have collected water samples from Sulphur Creek to estimate loading from mine sites and geothermal springs. Goff and coworkers (2001) collected water samples as part of a larger, collective database providing records on geothermal springs. Table 1.2 shows the mean and range of concentrations of total recoverable mercury in Sulphur Creek and tributaries.

Table 1.2 Mercury in Sulphur Creek Water Samples

Sampling Location (upstream to downstream)	Number of Samples (a)	Range of Concentrations Total Recoverable Mercury (ng/L)	Mean Concentration of Total Recoverable Mercury (ng/L)[b]
Upstream Clyde Mine	3	32 - 317	159
Downstream Clyde Mine	3	76 – 7,229	2,924
Upstream Elgin Mine[c]	3	358 – 21,917	8,535
Elgin Hot Spring	1	10,000	10,000
Downstream Elgin Mine	3	2,506 – 21,878	12,338
Sulphur Creek upstream from all mines except Elgin, Clyde, Rathburn, and Petray	3	330 – 1,879	**850**
Sulphur Creek upstream from West End Mine	4	342 – 3,422	**1,794**
Sulphur Creek downstream from West End Mine	6	230 – 3,894	**1,370**
Blanck Springs tributary input	6	635 – 2,110	1,334
Wide Awake Mine tributary input	6	2,450 – 15,243	5,841
Sulphur Creek downstream from Blanck Springs and Wide Awake Mine	6	351 – 17,360	**3,465**
Jones Fountain of Life Hot Spring	4	22,000 – 33,600	26,642
Unnamed tributary upstream from Elbow Springs	2	116 – 1,798	701
Sulphur Creek upstream of Wilbur Hot Springs	6	620 – 12,168	**3,753**
Sulphur Creek at the USGS gauge	34	303 – 16,411	**2,912**

(a) Foe & Croyle (1998), Suchanek, et al. (2004), Domagalski, et al. (2004), Goff, et al (2001), CVRWQCB, unpublished data.
(b) Values in bold are average concentrations from the main channel of Sulphur Creek.
(c) During a later survey, Regional Board staff observed geothermal springs and potential mine waste upstream of this sample site, suggesting that the "Upstream Elgin" site may not have been free of mine influence.

2 SOURCE ANALYSIS

2.1 Introduction

Sulphur Creek is in a region naturally enriched in mercury. Active geothermal vents and hot springs have deposited mercury, sulfur, and other minerals at or near the earth's surface. Sources of inorganic mercury now entering Sulphur Creek include mine waste from historic mercury mining operations, erosion of naturally enriched mercury soils, erosion of contaminated stream banks, runoff from geothermal springs, and atmospheric deposition of mercury. As a result, sediment in the bed and bank of Sulphur Creek is contaminated with inorganic mercury. All of these sources have exported mercury to Bear and Cache creeks leading to elevated concentrations of methylmercury in fish tissue.

The majority of mercury in Sulphur Creek comes from the Sulphur Creek Mining District. The mining district includes six inactive mines (Central, Empire, Wide Awake, Cherry Hill, West End and Manzanita) in the lower watershed and two inactive mines (Clyde and Elgin) in the upper watershed. Rathburn and South and North Petray mines are also located in the upper watershed but primarily drain east to Bear Creek.

Concentrations and loads of mercury and methylmercury discussed below refer to levels in unfiltered (raw) water. Very few data are available of total mercury and methylmercury in filtered samples. Most inorganic mercury in Cache and Bear Creeks is transported attached to sediment (Domagalski *et al.*, 2004). Slotton and colleagues (2004a) found that, of all relationships examined between mercury and biota in the Cache Creek watershed, the most significant correlations were between concentrations of methylmercury in unfiltered water and biota. Therefore, Regional Board staff relied on concentrations in unfiltered samples throughout this report.

In this section, a water budget for Sulphur Creek is presented followed by a mass balance of total mercury loads. The total mercury mass balance is based on water samples collected throughout the watershed during six storm events and is used for allocation of mercury loads (Section 5). The estimate of total loads from the mercury mass balance is validated by comparison with other calculations of mercury loads. These other calculations were made using additional water data collected at the USGS gauge. Contributions to the mercury loads from runoff of background, mercury-enriched, and mine site sediment, contaminated instream sediment, geothermal springs, and atmospheric deposition are also discussed. This section concludes with a calculation of methylmercury loads.

2.2 Water Budget

Flow is a critical component of calculating mercury and sediment load balances. Flow volume is multiplied by the concentration of each constituent in order to determine loads. The USGS operates one flow gauge on Sulphur Creek about one mile upstream of the confluence with Bear

Creek. Continuous flow data are available from this gauge for water years 2000 through 2003[2]. An analysis of flow data is presented in Table 2.1

Flow data are not available for any other part of the Sulphur Creek watershed and the rational method[3] of flow estimation could not be utilized because the nearby rain gauge was not accurately recording data during the period of record at the flow gauge. Flows from sampling sites in the watershed were estimated based on the size of the given drainage area relative to the area of the gauge site. Regional Board Staff used ArcView GIS software to calculate watershed areas from each of these sites in order to estimate flow. Flow estimates are listed in Appendix A.

Appendix A also shows the four years of flow recorded at the USGS gauge. Each graph depicts the average daily flow during one water year. The creek experiences 4-6 storm events per year that create peak flows. Storm events can increase flow to over 300 cfs in a few hours and flows then taper to average winter non-storm flow (<5 cfs) in the days following the event (USGS, 2004). Approximately 73 % of flow volume exported at the mouth of Sulphur Creek occurs during storm events and associated runoff (flows greater than 5 cfs). Flows greater than 5 cfs contribute to 15% of the yearly flow. California Department of Water Resources (DWR) classified water years 2000 and 2003 as above normal and water years 2001 and 2002 as dry years[4].

Table 2.1 Annual Flow Measured at USGS Gauge Site

Water Year	Average Daily Flow (cfs) [a]	Maximum Average Daily Flow (cfs)	Minimum Average Daily Flow (cfs)	Total Acre-feet/Year
2000	3.4	76	0.06	2,254
2001	2.0	93	0.05	1,439
2002	3.9	156	0.12	2,839
2003	4.6	140	0.11	3,307
(a) Data was accessed from the USGS water homepage (http://water.wr.usgs.gov/).				

Several geothermal springs flow into Sulphur Creek and their flows are included with flow measured at the gauge site. Average spring flow rates are listed in Table 2.5. Other components of the water budget include evaporation and groundwater; however, data are not available and their influence in the overall water budget is insignificant.

[2] A water year is defined as 1 October of the previous year through 30 September of the specified year. For example, the 1996 water year is defined as 1 October 1995 through 30 September 1996.

[3] The rational method equation is Q=CIA

Where:	Q = flow	I = rainfall
	C = runoff coefficient	A = watershed surface area

[4] DWR classifies water years based on an index of unimpeded runoff. For the Sacramento River Basin, runoff is measured at several points within the watershed. An “above normal” water year means the index is above 7.8 and equal to or less than 9.2. A “dry” water year means the index is above 5.4 and equal to or less than 6.5. More information on water year classification can be found on http://cdec.water.ca.gov/cgi-progs/iodir/WSIHIST.

2.3 Mercury Sources Entering Sulphur Creek

2.3.1 Mass Balance of Mercury in the Sulphur Creek Watershed

In order to identify sources of mercury measured at the gauge, concentrations of mercury and TSS were examined at multiple sites throughout the watershed on six occasions. Samples were collected by staff from UC Davis and United States Fish and Wildlife Service (USFWS) (Slotton, *et al*., 2004a and Suchanek, *et al*. 2004), and the Regional Board and DFG (unpublished data). All sampling events took place during or after storms. Not enough data are available from these six events to develop a statistical relationship between mercury concentrations and flow for the individual sites. As a result, site-specific average mercury concentrations from all events were multiplied by annual discharge to determine relative source load contribution to Sulphur Creek. As noted in Section 2.2, annual discharge was estimated at each site using the acreage of the drainage area at each site relative to drainage area at the USGS flow gauge and developing a proportional value of discharge volume. Table 2.2 summarizes the four-year average load from specific points in the watershed as well as the percent contribution from each site. Figure 2.1 provides a conceptual diagram of mercury loads from each sub-watershed relative to acreage in their respective basins. Appendix B lists data used in the load calculations.

Table 2.2 Sulphur Creek Mercury Loads

Site (Upstream to Downstream)	Average Annual Mercury Loads (kg/yr)[a]	Percent Contribution to Loads Exported at USGS Gauge
Tributary Loads		
Upper Watershed (East Branch, Salt Branch, mainstem Sulphur to West End)	1.2	10%
Clyde Mine sub-watershed (Freshwater Branch)	0.4	3%
Elgin Mine sub-watershed (West Branch)	2.7	22%
Blanck Springs tributary	0.02	0.2%
Wide Awake Mine tributary	0.8	7%
Empire Mine tributary	0.1	1%
Sum	5.3	44%
Mainstem Loads[b]		
West End Mine sub-watershed	-0.9	-7%
Manzanita Mine sub-watershed	4.8	40%
Central Mine sub-watershed	1.9	16%
Wilbur Springs sub-watershed	0.8	7%
Sum	6.7	56%
Load at USGS Gauge[c]	12.0	

(a) Appendix C provides a more detailed table of how load estimates were calculated.
(b) These are not loads coming from specific mine sites. Samples were collected upstream and downstream of the mine sites and these names are used as landmarks in order to determine instream loads between sites along the mainstem of the creek.
(c) The difference in load from downstream to upstream of West End Mine equals –0.9 kg/yr, which suggests no mercury load comes from this section of the creek. This portion of the creek may be a depositional area and may be a load source, depending on storm events. Churchill and Clinkenbeard (2004) describe this area as being erosional with elevated concentrations of mercury in hillside sediments.

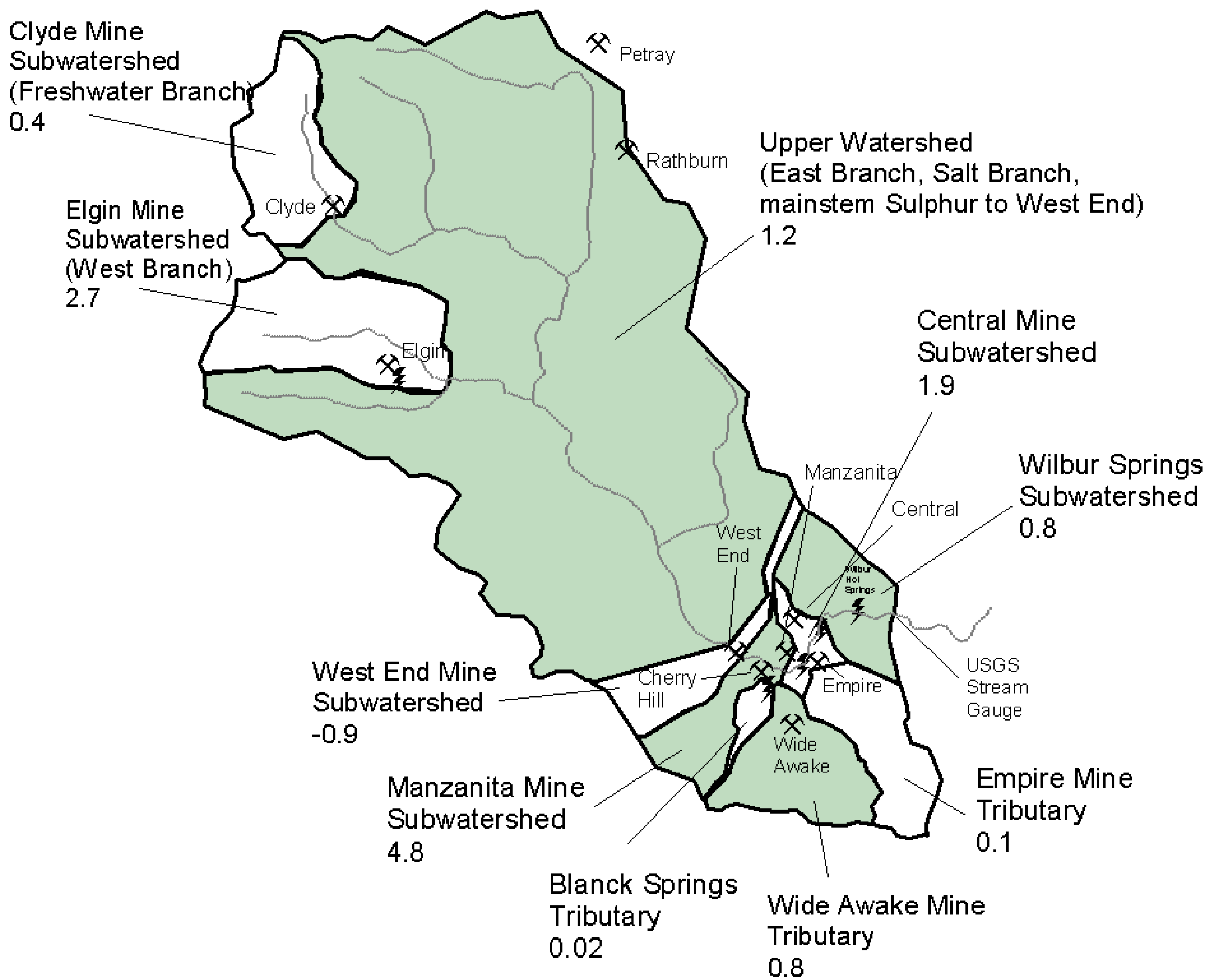

Figure 2.1 Sulphur Creek Sub-watershed and Tributary Loads (kg/yr)

Loads from tributary inputs total 5.3 kg/yr, which account for 44% of the load exported out of Sulphur Creek. Upper watershed sources account for 9% of the total Sulphur Creek load. The upper watershed includes the East Branch, Salt Branch, the West Branch and Freshwater Branch downstream of Elgin and Clyde mines, respectively, and to upstream of West End Mine. Storm events limit accessibility and better source identification to this large portion of the Sulphur Creek watershed. Mercury sources in the upper watershed come from erosion of background and mercury enriched soil and resuspension of previously deposited instream sediment contaminated by mercury. Petray and Rathburn mines are located in the East Branch but current runoff from these sites likely flows into Bear Creek and not Sulphur Creek. Initial workings at the Rathburn and Petray properties, road cuts, or unnamed mine prospects may have contributed to contaminated sediment in the East Branch. In the water years represented by this budget, it appears that loads from non-mineralized areas (mostly in the Upper Watershed) are small, relative to other sources.

West Branch, where the Elgin Mine is located, contributes the largest load (2.7 kg/yr) of all the tributary sources, accounting for 22% of the mercury load leaving Sulphur Creek. Samples were collected upstream and downstream of Elgin Mine and the difference in the load averages 1.2 kg/yr (Appendix C), accounting for 44% of the West Branch load. Samples collected upstream of Elgin Mine may not have been out of the zone of mine influence and the load contribution from the site may actually be higher. Freshwater Branch, where Clyde Mine is located, contributes 3% of the mercury load exported out of Sulphur Creek. The load difference between upstream and downstream of the mine averages 0.4 kg/yr, accounting for 95% of the load within Freshwater Branch. Sources of mercury from upstream of both mine sites come from background and mercury enriched sediment runoff. Based on erosion rates, Churchill and Clinkenbeard (2004) estimate between 3.9 and 9.3 kg/yr of mercury are mobilized from Elgin Mine site features and 0.04 to 0.07 kg/yr mercury come from Clyde Mine site features.

The tributaries where Empire and Wide Awake mines are located contribute 1% (0.1 kg/yr) and 7% (0.8 kg/yr) of the Sulphur Creek load, respectively. Mercury sources from the tributaries include runoff from mine sites, enriched soil and background soil. Samples were not collected upstream of the mine sites so specific mine load contributions (less background) could not be estimated. For comparison, Churchill and Clinkenbeard (2004) estimate between 0.02 and 0.44 kg mercury are delivered to the tributary from Wide Awake Mine features and between 0.04 and 0.06 kg mercury come from Empire Mine features per year.

Mercury loads in the mainstem of Sulphur Creek between downstream of West End Mine to the USGS stream gauge average 6.7 kg/yr, accounting for 56% of the load (Table 2.2).

The mainstem portion of the creek from upstream to downstream of West End Mine appears not to be a source of mercury. Four sampling events were conducted to determine West End Mine contributions. Half of the samples had larger mercury concentrations upstream than downstream of West End Mine. However, Churchill and Clinkenbeard (2004) estimate that West End Mine contributes as much as 1.1 kg of mercury each year to the creek based on erosion estimates.

The largest portion of the mainstem load comes from the section between downstream of West End Mine and upstream of Wilbur Hot Springs and accounts for 56% of the total load

(Table 2.2). Sources of mercury from this area come from stored sediment in the creek that is remobilized during storm events, Jones Fountain, Elbow springs, instream geothermal springs, and runoff from Manzanita and Central mines, mercury enriched soil and background soil. Based on erosion calculations, between 0.3 and 6.5 kg mercury per year come from Manzanita Mine and between 0.003 and 0.03 kg/yr mercury come from Central Mine features (Churchill and Clinkenbeard, 2004). Mercury load contributions from Cherry Hill Mine are unknown.

Loads between upstream of Wilbur Springs to the outflow at the gauge account for 7% of the Sulphur Creek load. Sources of mercury in this portion of the creek include instream sediment remobilized during storm events, Wilbur Springs, and runoff from background and mercury enriched soils.

2.3.2 Mercury in Runoff

All of the sites within Sulphur Creek accumulate mercury in runoff. Mercury from runoff derives from three sources: mine sites, mercury enriched (mineralized) areas, and from soil containing background concentrations of mercury. Churchill and Clinkenbeard (2004) estimate between 5.4 and 39.9 kg/yr comes from runoff with most of the load coming from mine site features (Table 2.3). The term, “mineralized areas”, describes the soil and rock that is enriched in mercury as part of a mercury deposit, but was undisturbed by mining operations. Although mercury concentrations can be high, loads from the undisturbed mineralized area are small because the surface areas of the zones are small.

Table 2.3 Mercury Loads from Mine Sites, Background Soil, and Mineralized Areas (kg/yr)[a]

	Minimum Mercury Load	Percent Contribution	Maximum Mercury Load	Percent Contribution
Mine Site Contribution[b]	4.4	81%	18.6	47%
Background Soil	0.9	17%	19.7	49%
Mineralized Areas	0.08	1%	1.6	4%
Total	5.4		39.9	

(a) Data from Churchill and Clinkenbeard (2004).
(b) Without Rathburn and Petray Mines.

Mine sites contribute between 47 and 81 percent of the mercury load. Areas disturbed by mining account for 230 of the 6543 acres in the Sulphur Creek watershed. Undisturbed, mercury enriched areas account for 120 acres in the watershed, which have soil mercury concentrations that range up to 1000 times higher than regional background. Background soil may contribute a large portion of runoff due to the relative amount of acreage; however, the actual amount of mercury delivered to the creek from all runoff is unknown. Churchill and Clinkenbeard (2004) believe that only a small portion actually enters Sulphur Creek and loads are closer to the lower estimate. Erosion from these features may be immobilized by grass cover and redeposit on the hillsides.

Churchill and Clinkenbeard’s (2004) method used to estimate loads of mercury in mine site, mineralized soil and background soil runoff (Table 2.3) is different than the watershed-based load estimates in Table 2.2 prepared by Regional Board staff. As described above, the watershed mass balance estimates were developed using instream mercury concentration data collected at multiple points in the watershed and stream flow rates based on relative size of the sub-watershed draining to the sampling point. Churchill and Clinkenbeard (2004) estimated runoff from mine waste rock piles, tailings piles and other land features using primarily the Revised Universal Soil Loss Equation (RUSLE). The RUSLE model incorporates local information regarding temperature, rainfall, slope steepness and length, soil type and vegetative cover to produce estimates of average annual soil loss. The ranges in estimates in Table 2.3 are due to use of minimum and maximum estimates of the soil erosion rate for each area. Both methods provide valuable information about mercury transport in the Sulphur Creek watershed. The two load estimates may not coincide because of variability in erosion and length of time for eroded material to reach the creek.

2.3.3 Instream Sediment Mercury Concentrations

Geothermal precipitates and runoff from background soil, mineralized areas, and mine sites deposit mercury laden sediment to the active channel in Sulphur Creek. Sediments within the creek provide a source of mercury to downstream areas during storm events. High flows disturb and remobilize mercury-contaminated sediment, which are either redeposited instream or moved out of the creek. Several instream sediment samples have been collected in the mainstem of Sulphur Creek and in the tributaries of the upper watershed (Figures 2.2 and 2.3). The purpose of stream sediment sampling was to examine mercury concentrations and potential sources in areas of the watershed that are inaccessible during storm events. The concentrations of mercury in fine-grained stream sediment can be compared with concentrations of mercury in suspended sediment (Hg/TSS ratio). Tetra Tech (2004) describes observing tailings or waste rock exposed by the Sulphur Creek channel and within the floodplain near the Manzanita and Cherry Hill mines.

Samples collected on the East Branch, downstream of Rathburn and Petray mines contained 3.0, 6.4 and, 9.2 mg/kg mercury, suggesting that the mines or other sources may contribute to elevated instream mercury concentrations. Other possible sources of elevated mercury in this portion of the creek may be runoff from the several road cuts in the area, runoff from unidentified mercury enriched soil, or activities at unnamed mine prospects. Sediment samples on the Freshwater Branch, downstream of the Clyde Mine, have similar concentrations to those on the East Branch, with 2.0 and 3.0 mg/kg mercury. Instream sediments on the West Branch near Elgin Mine are highly contaminated with mercury and have the potential to be transported down the creek. Samples collected on this tributary range from 3.5 mg/kg upstream of Elgin Mine up to 327 mg/kg near the mine site to 33 and 41 mg/kg at the confluence with the Freshwater Branch. Salt Branch has no mines in its watershed and is a tributary to the West Branch. Sediment samples from this tributary contain 0.4 and 1.1 mg/kg mercury.

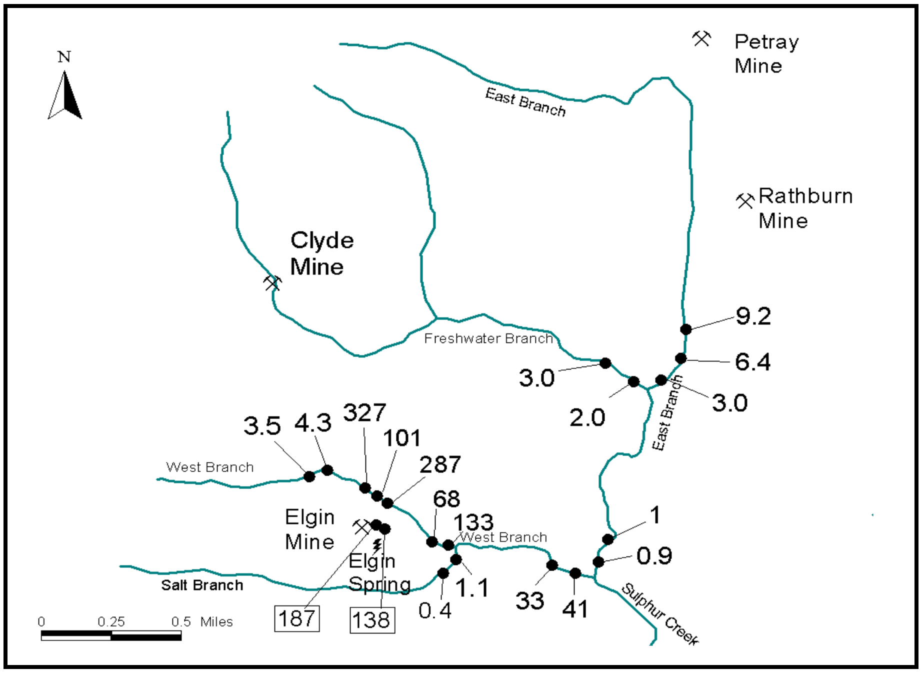

Figure 2.2 Fine Sediment Instream Mercury Concentrations (mg/kg) in the Upper Watershed of Sulphur Creek. Values enclosed in a box are samples from geothermal spring "muck". (Source data: Goff *et al*. 2001 and CVRWQCB, unpublished data)

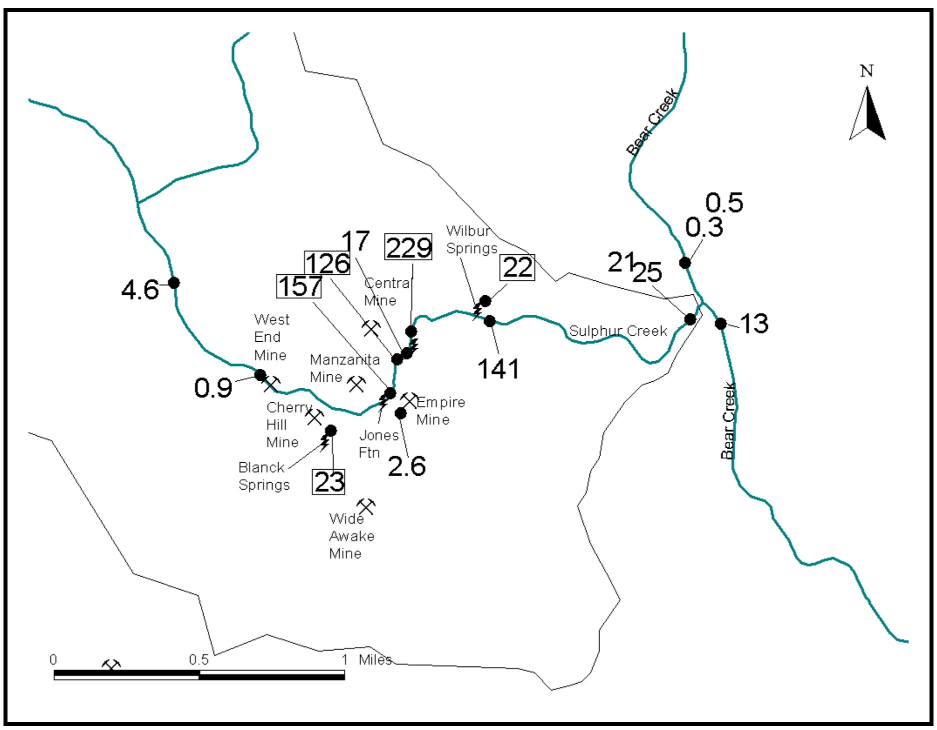

Figure 2.3 Fine Sediment Instream Mercury Concentrations (mg/kg) in the Lower Watershed of Sulphur Creek. Values enclosed in a box are samples from geothermal spring "muck". (Source data: Goff *et al*. 2001 and CVRWQCB, unpublished data)

Mercury concentrations in samples collected in mainstem Sulphur Creek vary widely. Concentrations range between 4.6 mg/kg upstream of West End Mine to 0.9 mg/kg near Manzanita Mine and 141 mg/kg near Wilbur Springs to 21 and 25 mg/kg at the mouth of Sulphur Creek. Samples were also collected upstream and downstream of the Sulphur Creek confluence on Bear Creek. Bear Creek upstream samples measure 0.3 to 0.5 mg/kg (near background concentrations) while downstream of the confluence contains 12.9 mg/kg.

2.3.4 Mercury to Suspended Sediment Ratio

As previously noted, the concentration ratio of mercury to suspended sediment (Hg/TSS) in water is a measure of mercury contamination in surficial sediment. Sulphur Creek regional background concentrations range between 0.07 and 0.31 mg/kg in soil (Churchill and Clinkenbeard, 2004). Mercury concentrations in soil naturally enriched with mercury averaged 1.6 mg/kg (Churchill and Clinkenbeard, 2004 and Pearcy and Petersen, 1990).

Hg/TSS ratios from all samples collected at the flow gauge range between 6.1 and 384.3 mg/kg and average 51.6 mg/kg. Hg/TSS samples collected using a Sigma Autosampler ranged between 22.6 and 170.7 mg/kg prior to the storm event on February 25, 2004 (Appendix G). As storm flows subside, concentrations range between 4.2 and 8.7 mg/kg (Figure 2.4).

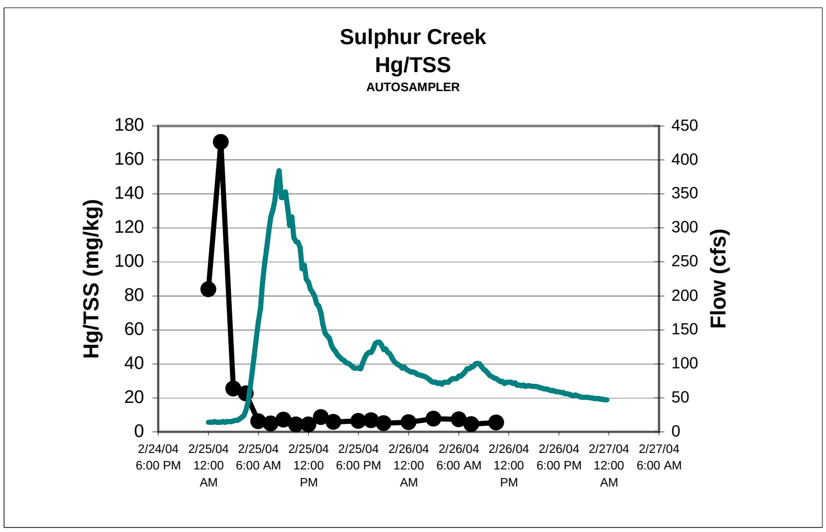

Figure 2.4 Mercury to TSS Ratios Compared to Flow During One Storm Event in Sulphur Creek

The change in Hg/TSS over time is likely evidence of the multiple types of mercury sources in Sulphur Creek. Precipitates from the geothermal springs are flocculent, have high mercury concentrations, and would likely mobilize quickly with a small increase in flow (Rytuba, 2000). The lower Hg/TSS levels observed during most of the storm are likely indicative of mercury from the mine sites and contaminated stream banks. Supporting this observation that Hg/TSS concentrations are also high in the summer, when low flows are dominated by geothermal outputs.

2.3.5 Sulphur Creek Baseline Flows and Loads – Geothermal Input

Several geothermal springs flow into Sulphur Creek and for most of the year account for the base flow. Wilbur Hot Springs, Jones Fountain of Life, and Blanck and Elbow springs are some of the larger known geothermal sources with smaller springs bubbling up within the creek. The springs contribute to a portion of the total mercury load to Sulphur Creek.

Historic flows recorded at the USGS stream gauge between May 15 and November 15 are assumed to represent flows from all geothermal spring sources, as rainfall during this period is rare. Flows range between 0.05 and 1.9 cfs with a median of 0.23 cfs. Ninety-four percent of the summer flows range between 0.1 and 1 cfs. Churchill and Clinkenbeard (2004) report site-specific flow from all the named hot springs total 0.08 cfs. Flow from unknown and instream geothermal springs may account for the difference in flow at the gauge site.

Seven water samples collected at the gauge for mercury analysis between May 15 and November 15 from multiple sampling years represent average summer concentrations. Concentrations range between 676 and 1320 ng/L and average 942 ng/L. Average mercury concentrations were multiplied by the median flow in order to determine mercury loads from geothermal sources. Total mercury loads range between 139 and 271 g/yr with an average of 193 g/yr (Table 2.4). In comparison, Churchill and Clinkenbeard (2004) estimate geothermal mercury loads range between 170 and 290 g/yr.

Table 2.4 Annual Mercury Loads from Geothermal Springs

	Average	Minimum	Maximum
Total Mercury Concentration (ng/L) n = 7	942	676	1320
Total Mercury Load (g/yr)	**193**	**139**	**271**
Median Flow at USGS stream gauge (cfs)	**0.23**		

Table 2.5 provides site-specific geothermal spring flows, concentrations and loads. Total mercury loads from named springs contribute an average of 731 g/yr to Sulphur Creek, which is a higher estimate than loads calculated at the USGS gauge. Instream deposition and spring precipitates that settle in the creek may account for the difference. Jones Fountain, Wilbur Hot Springs, and Elgin Spring contribute the largest geothermal mercury loads. Mercury precipitates from geothermal springs may actually be a larger source of mercury on an annual basis than mercury measured in spring fluid (Churchill and Clinkenbeard, 2004 and Domagalski, *et al*., 2004). Precipitates downstream of geothermal vent areas contain between 1 – 300 mg/kg mercury. They accumulate during the summer and are flushed downstream during winter high flow events.

Table 2.5 Site Specific Mercury Loads from Geothermal Springs

Spring	Flow (cfs)	Average Hg Concentrations (ng/L)[a,b]	Geothermal Hg Loads (g/yr)
Blanck	0.008	6,900	49
Elbow	0.0003	61,000	16
Jones Fountain	0.012	26,642	286
Wilbur Hot Springs	0.047	5,556	233
Elgin[c]	0.015	11,000	147
Total	**0.083**		**731**

(a) Wilbur Springs and Jones Fountain are the only sites where multiple samples have been taken and these values represent their average concentrations. Data from these sites are in Appendix D. All other spring sites have one sample measurement.
(b) Sources include: Rytuba, 2000; Goff *et al*., 2001; Suchanek *et al*., 2004; unpublished data collected in 2003 and 2004 by Regional Board and DFG staff.
(c) Elgin Spring is located in the upper Sulphur Creek watershed. Flows likely don't enter into the mainstem of Sulphur Creek during the summer.

Neither geothermal spring estimate accounts fully for the mercury that is thought to be discharged from the geothermal springs in the lower watershed. The estimate of annual contribution at the gauge, which is based on summer (i.e., non-runoff) concentrations, does not account for the load from precipitates, which are mobilized in higher flows (Churchill and Clinkenbeard, 2004). The estimate of loads from spring orifices includes much of the mercury that precipitates, but does not include the springs within the stream bed, which have not been measured. To account for the precipitates and non-measured springs, Regional Board staff doubled the sum of loads from individual springs in the lower watershed for a total geothermal spring input estimate of about 1.4 kg/yr. This total estimate for lower watershed springs is used in the load allocations (Section 5).

2.3.6 Atmospheric Deposition

Atmospheric loads of mercury derive from global, regional, and local sources. Atmospheric input is the wet and dry deposition falling directly to water surfaces and indirect deposition on the terrestrial watershed with subsequent runoff during storms. Evaluating the atmospheric inputs is important to understand the significance of atmospheric deposition relative to other sources. Modulating deposition from the global/regional atmospheric sources is beyond the regulatory ability of the Regional Board.

Regional Board staff used similar methods in determining atmospheric mercury loads to Sulphur Creek as were estimated in Cache Creek (CVRWQCB, 2004). First, estimates are calculated for mercury that deposits to the surface of Sulphur Creek itself. Second, estimates are made for the amount of mercury deposited on the Sulphur Creek watershed that reaches the creek in runoff.

Annual deposition to the surface of Sulphur Creek ranges between 0.09 and 0.19 g/yr. This range is derived from estimates of wet and dry deposition at Covelo, CA (minimum value of 3.9 ng/L; NADP, 2000a,b) and San Francisco (maximum value of 8 ng/L; SFEI, 2001) multiplied by the average annual rainfall at Sulphur Creek. Dry deposition rates are assumed to be equivalent to wet (SFEI, 2001). The contributions directly to the creek are so low that they are considered insignificant to the total annual load. See Appendix E for complete calculations.

Atmospheric deposition that does not fall directly to the creek but falls within the watershed is accounted for in samples collected during periods of storm runoff. To estimate the amount of mercury from the atmosphere to the watershed that reaches Sulphur Creek, Regional Board staff applied the rates of mercury deposition and average annual precipitation described above to the area of the entire Sulphur Creek watershed. The watershed area of 6543 acres is estimated to receive 70-144 g/year of mercury from the atmosphere. Assuming 10% of the terrestrial load is transported into waterways (Dolan *et al.*, 1993; SFEI, 2001) the indirect atmospheric contribution to loads in Sulphur Creek is 7-14 g/year. This estimate is not identified separately because the atmospheric loads would be counted twice (i.e., the runoff of atmospheric mercury into Sulphur Creek is already accounted for in load estimates in Table 2.2). Atmospheric contributions to the Sulphur Creek watershed are nominal compared to other sources.

2.4 Comparison Estimates of Total Mercury Loads

2.4.1 Mercury loads at the USGS stream gauge

Section 2.3.1 describes the calculation of mercury loads throughout the Sulphur Creek watershed based on six storm events. Additional data has been collected at the USGS stream gauge in order to quantify mercury loads exported from the watershed (Foe and Croyle, 1998; CVWQCB, 2004 and unpublished data; Domagalski *et al*. 2004; Slotton *et al*. 2004a; Suchanek *et al*. 2004). Samples were collected during both non-storm and storm events between 1998 and 2004. A few storm sampling events captured some of the highest concentrations and loads exported out of Sulphur Creek in this time span however, these years are not classified as “wet” years. Larger storm events could remobilize and transport even larger mercury loads. Concentrations of total mercury range between 245 and 16,411 ng/L, with an average concentration of 2890 ng/L (n = 34). A positive correlation exists between total mercury concentrations and flow (r2= 0.49, p<0.0001) (Appendix F). The linear equation derived from the regression analysis is used to estimate a flow-weighted concentration on days where mercury samples were not collected but flow data are available.

Annual mercury loads are calculated by multiplying the mean daily flow by the flow-weighted mercury concentration and summing over the year. Mercury loads range between 3.7 and 12.3 kg/yr with an average of 8.0 kg/yr. Suchanek *et al* (2004) estimated mercury loads ranged between 0.6 and 10.7 kg/y for water year 2000 and 0.6 and 17.1 kg/yr for water year 2001. These load estimates are comparable to the load calculated in the mass balance in Table 2.2.

2.4.2 Mercury samples collected using a Sigma Autosampler

Regional Board staff installed a Sigma Autosampler at the USGS gauge prior to a storm event to collect water samples every 90 minutes between the 25th and 26th February 2004. The samples were analyzed for total mercury and TSS in order to determine the nature of mercury and sediment loading during storm events. Instantaneous flow values for every quarter hour during the storm were accessed from the USGS website in order to develop load estimates. Laboratory results and flow values are in Appendix G.

Figure 2.5 shows total mercury concentrations peaking on the leading edge of the storm prior to peak flows and ebbing as flows subside. Figure 2.6 shows peak loads coinciding with peak flows. As flows subside, mercury loads return to levels similar to the pre-storm event. Regional Board staff estimates that during this 36-hour period of sampling 1.6 kg mercury were exported out of Sulphur Creek. Between 6.4 and 9.6 kg of mercury would be exported annually during storm events considering that Sulphur Creek experiences between 4 and 6 major storms per year. This range is similar to load estimates discussed above.

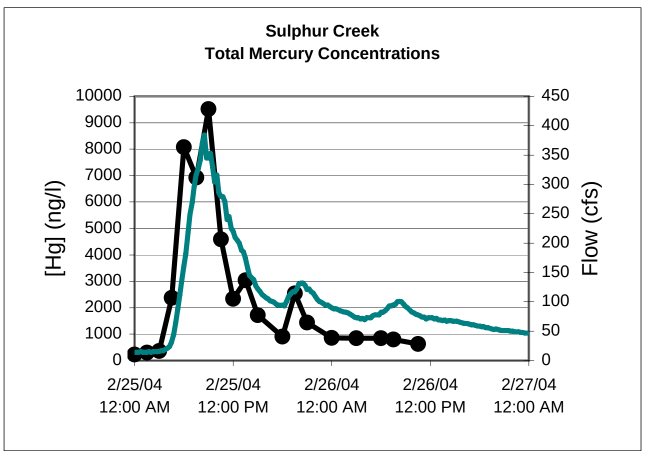

Figure 2.5 Total Mercury Concentrations Compared to Flow in Sulphur Creek Collected by a Sigma Autosampler.

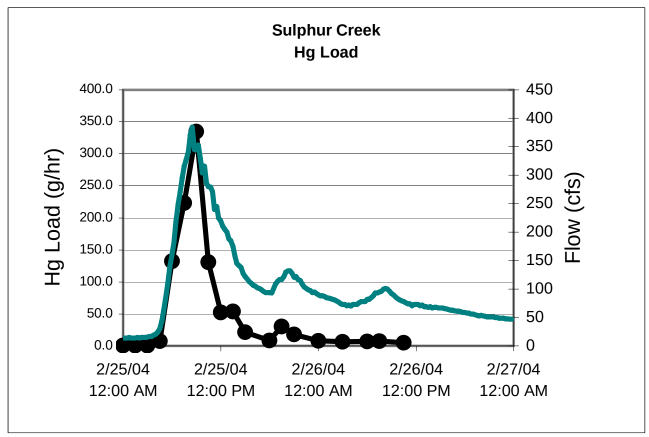

Figure 2.6 Total Mercury Loads Compared to Flow in Sulphur Creek Collected by a Sigma Autosampler.

2.5 Methylmercury Exports from Sulphur Creek

Sulphur Creek exports methylmercury to Bear Creek where fish have elevated concentrations of methylmercury. Approximately 40% of the total methylmercury load in Bear Creek comes from Sulphur Creek (CVRWQCB, 2004).

Methylmercury samples were collected at the Sulphur Creek USGS stream gauge during several sampling events that took place between 2000 and 2004 (CVWQCB, 2004 and unpublished data; Domagalski *et al*. 2004; Slotton *et al*. 2004a; Suchanek *et al*. 2004) in order to estimate methylmercury loads. Methylmercury concentrations range between 0.06 and 20.6 ng/L, with an average of 2.5 ng/L (Bear Creek concentrations average 0.65 ng/L at Hwy 20). The highest concentrations were measured in the months of July and August. A positive relationship does not exist between methylmercury concentrations and flow so loads could not be estimated using regression analysis. To determine methylmercury loads the mean concentration from all samples collected at the gauge site was multiplied by average annual flow. Methylmercury loads exported out of Sulphur Creek range between 4.3 and 10.0 g/yr (Table 2.6).

Table 2.6 Sulphur Creek Methylmercury Loads

Water Year	Yearly Flow (ac-ft/yr)	MeHg Load (g/yr) using mean value (2.5 ng/L)
2000	2254	6.8
2001	1439	4.3
2002	2771	8.4
2003	3307	10
Average	2443	7.4

Methylmercury samples were also collected throughout the Sulphur Creek watershed at the same sites as total mercury samples; however, too few data are available to estimate loads or to determine areas of methylation. Methylmercury samples from all of the tributary inputs range between 0.3 and 1.8 ng/L (one Jones Fountain sample contained 13.5 ng/L) while samples in the mainstem range between 0.6 and 1.9 ng/L methylmercury.

3 NUMERIC TARGET

3.1 Definition of a Numeric Target

Numeric targets are the specific goals for the TMDL that will enable the protection of the Sulphur Creek beneficial uses. As discussed below, the numeric target for this TMDL is the mercury concentration in fine-grained sediment that is intended to return the watershed to preanthropogenic conditions.

3.2 Existing Uses of Sulphur Creek

Beneficial uses of Cache Creek, which may be applied to Sulphur Creek, were shown in Table 1.1. The following paragraphs describe the existing uses of Sulphur Creek.

Municipal, Domestic, and Industrial Supply

Regional Board staff is unaware of any direct municipal and domestic supply use of water from Sulphur Creek since 1975[5]. The Wilbur Hot Springs resort obtains drinking water from shallow groundwater wells on a ridge above Sulphur Creek. Sulphur Creek flows to Bear Creek and into Cache Creek, which is designated for municipal and domestic supply. However, Sulphur Creek is estimated to provide less than one percent of the flow volume of Cache Creek at the town of Yolo (CVRWQCB, 2004). There are no industrial uses of Sulphur Creek water.

Stock watering

Sulphur Creek is used for stock watering. Cattle graze in the watershed upstream of Wilbur Hot Springs and drink from Sulphur Creek. There are no other agricultural uses of creek water within the Sulphur Creek watershed.

Wildlife Habitat

Sulphur Creek provides some wildlife and aquatic habitat. Terrestrial mammals, such as wild boar, raccoon, coyote and deer drink from the creek. Regional Board staff has observed California newts, frogs, snakes, and turtles in the creek.

Fish Spawning, Reproduction and/or Early Development

Cache Creek is designated as habitat for spawning and early development of anadromous fish species in cold (salmon and steelhead) and warm water (American shad, striped bass, and

[5] The Federal Clean Water Act became law in 1975. This date is used as a benchmark for defining existing uses of a waterbody. Conditions or uses existing in or after November 1975 must be protected and maintained.

sturgeon). Sulphur Creek does not provide water of sufficient quantity and quality for spawning by these species (Moyle, 2004). Low water flow, high year-round temperatures, and high mineral content from the geothermal springs would deter their spawning. Reproduction by other aquatic species is covered under the aquatic life and freshwater habitat use designations.

Warm Freshwater Habitat

The use of Sulphur Creek by fish is thought to be opportunistic. Low summer flows and heat and high dissolved solids from geothermal inputs, and high suspended solid concentrations in winter storms likely limit fish use. In May 1998, one California roach was caught from Sulphur Creek near the Bear Creek confluence for analysis of mercury (Slotton *et al.*, 2004a). This fish may have originated in Sulphur Creek or Bear Creek. In April 2004, staff from the DFG and the Regional Board electroshocked Sulphur Creek from Jones Fountain of Life to the confluence with Bear Creek in order to evaluate its aquatic resources (DFG, 2004). CDFG staff found no fish. In the course of his own work, UC Davis fisheries biologist Peter Moyle has examined Sulphur Creek a number of times and also observed no fish (Moyle, 2004).

Aquatic Life

Sulphur Creek provides habitat for invertebrates. UC Davis researchers evaluated mercury in benthic macroinvertebrates collected from Sulphur Creek near the gauge site in 1996 and in 2000-2001 (Slotton *et al*., 1997; 2004a). USGS scientists collected macroinvertebrates upstream of Wilbur Springs in 1997 and 1998 (Schwarzbach *et al*., 2001). Benthic macroinvertebrates have been identified from the following taxa: Naucoridae (creeping water bugs) and nymphs or larvae of zygoptera (damselflies), ephemerellidae (mayflies), siphlonuridae (swimming mayflies), hydropsychidae (net caddis flies), and sialidae (alderflies). Benthic invertebrates and the corresponding adult stages of insects may provide food for nesting birds. USGS researchers hypothesized that brine flies, which are abundant around Sulphur Creek in the summer, were likely prey of killdeer nesting nearby.

Contact and Non-Contact Recreation

Humans do not fish in Sulphur Creek because fish are lacking. The Wilbur Hot Springs resort proprietors have not observed angling in the watershed. Geothermal waters from Wilbur Hot Springs and other springs are used for bathing. The pools and tubs are connected directly to the hot springs and are not filled with water drawn from the creek. Bathing in natural hot spring water is an established recreational use. Non-contact recreational uses of Sulphur Creek such as hiking and aesthetic enjoyment also exist.

3.3 Numeric Targets

3.3.1 Justification for Proposal of a Natural Background Target

This TMDL proposes a numeric target for mercury in sediment based on natural or background concentrations. This target is proposed because there are significant natural inputs of mercury to Sulphur Creek that are unrelated to anthropogenic activities. These inputs from naturally enriched soils and geothermal springs cause mercury levels in Sulphur Creek to be elevated relative to most water bodies in the Central Valley.

Geothermal inputs are a natural feature of the creek that existed prior to mining and development activities. At the Wilbur Hot Springs Resort, water from two geothermal springs is piped into the resort pool and baths and flows back to the creek. These springs are located on the bank of Sulphur Creek and would have flowed directly to Sulphur Creek prior to construction of the resort.

Aquatic life in Sulphur Creek has presumably adapted to the high mineral content and temperatures caused by inputs from the geothermal springs. As discussed above, the geothermal inputs and naturally mercury-enriched soils existed prior to anthropogenic activities. It is unknown whether the creek assemblage has changed following construction and operation of the road, mines, and resort. The intent of this TMDL and the natural background target is to return the creek to preanthropogenic conditions. Implementation of the TMDL should improve water quality and potentially expand the variety of aquatic species using Sulphur Creek, as well as reducing loads and improving water quality in Bear Creek.

Establishing water quality standards based on natural background conditions are permissible under USEPA's Water Quality Regulations. Section 131.10, Subparagraph (g) of the Code of Federal Regulations states the following:

> "States may remove a designated use which is not an existing use, as defined in Section 131.3, or establish sub-categories of a use if the State can demonstrate that attaining the designated use is not feasible because: (1) Naturally occurring pollutant concentrations prevent the attainment of the use. (40 CFR 131.10).

A numeric target based on natural background conditions should protect all wildlife, aquatic, stock watering and human contact and non-contact recreational beneficial uses of Sulphur Creek. In Sulphur Creek, naturally occurring concentrations of mercury in the water may prevent attainment of existing drinking water quality objectives. As previously noted, the goal of this TMDL is to return the creek to preanthropogenic conditions. Regional Board staff will propose that for this TMDL, the numeric target will be based on natural background conditions. The implementation plan (see Section 7) is designed to meet the target. After the mines and creek sediments have been remediated, staff will evaluate compliance with the numeric target and existing numeric water quality objectives. If after all reasonable and feasible control actions have been implemented and the existing water quality objectives have not been met, then staff will propose to modify the beneficial uses of Sulphur Creek through a formal Basin Plan amendment. The proposed beneficial uses for Sulphur Creek would encompass the uses described in section 3.2 and would include aquatic life, wildlife habitat, freshwater habitat, agriculture/stock watering, and contact and non-contact recreation. Regional Board staff would propose that Sulphur Creek not be designated for municipal and domestic supply or spawning of anadromous fish species. Any decisions related to designation of uses for Sulphur Creek will be undertaken in a formal public process.

3.3.2 Regional Background Sediment Target

Regional Board staff is proposing a sediment target based on the natural or background concentration of mercury in the Sulphur Creek watershed. This target is applicable to areas of the watershed that are not within the mineralized zones and is termed the regional background. Mineralized zones are enriched in mercury by geologic processes and include the geothermal springs or mining areas. Separate cleanup goals for the mine sites are discussed below.

The proposed regional background target is 0.2 mg/kg dry weight in fine-grained sediment. This value is the average concentration in soil samples collected at the periphery of the Sulphur Creek watershed (Churchill and Clinkenbeard, 2004) and non-mineralized soil near mined areas in lower Sulphur Creek (Pearcy and Petersen, 1990)[6]. The proposed target may be refined if additional samples are collected, such as during a remediation feasibility study. The regional background target level is consistent with concentrations of mercury in fine-grained sediment in adjacent watersheds of North Fork Cache Creek and upper Bear Creek, which had little or no mercury mining activities (CVRWQCB, 2004).

3.3.3 Preliminary Goal for Soil from Mineralized Zones

Concentrations of mercury in undisturbed soil on and adjacent to the mine sites are expected to be higher than the proposed regional background target. As described by State geologists Churchill and Clinkenbeard,

> "The natural hydrothermal processes that form mercury deposits typically enrich the surrounding host rocks in mercury for some distance outward from the deposit. These distances may range from less than a meter to hundreds of meters and the degree of enrichment in mercury content is often one to two orders of magnitude above the natural regional background…Weathering of these enriched mercury rocks produces elevated mercury regolith (unconsolidated material overlying solid rock) that may be subject to erosion and transport through the watershed."
> *Churchill and Clinkenbeard, 2004, page 11.*

Homestake Mining Company has mapped the mineralized zone around mines in the lower Sulphur Creek valley. Concentrations of mercury in soil were 1.6-3.2 mg/kg at the periphery of the mineralized zone. Smaller pockets were found containing at least 15 mg/kg mercury in the mineralized zone bounding the creek (West End, Cherry Hill, Empire, Manzanita and Central Mines) and at least 30 mg/kg at Wide Awake Mine (Pearcy and Petersen, 1990). Concentration

[6] Homestake Mining Company analyzed mercury in rock chips collected from 94 locations on and around the Cherry Hill, Manzanita, West End, Wide Awake, Central and Empire mines as part of a mineral exploration program. Summary data are reported in Pearcy and Petersen (1990).

patterns followed the trend of faults underlying the Wilbur Springs area (Pearcy and Petersen, 1990). Churchill and Clinkenbeard (2004) collected samples of soil believed to have been undisturbed by mining (i.e., local background) at Clyde, Elgin, and the Sulphur Creek valley mine sites. Concentrations ranged from 0.79 mg/kg to 330 mg/kg (Churchill and Clinkenbeard, 2004).

Data are lacking to propose numeric targets for the mineralized zones. As described above, mineralized zones at each mine site vary in terms of range of concentrations and soil types. Local background samples collected from the Elgin mine site all contained greater than 100 mg/kg mercury, suggesting that the extent of the zone and minimum concentrations in the Elgin mineralized zone are not known. A first step to development of a cleanup plan for each mine will likely be to map soil mercury concentrations in detail. From a soil concentration map and analysis of erosion potential, estimates of loads from the local background soil could be made for each mine site.

A proposed preliminary cleanup goal for mercury in soil transported off of the Sulphur Creek mine areas is 3 mg/kg, which is approximately double the concentration found at the periphery of the mineralized zone in the lower watershed (Pearcy and Petersen, 1990). This preliminary cleanup goal should be refined when soil data are gathered for each mine site. Cleanup goals for the mine sites apply to fine-grained sediment collected in runoff and from the stream bed below the mine sites.

3.3.4 Comparison of Target with Sediment at the USGS Gauge

It is difficult to estimate the concentration of mercury in sediment (or its associated measurement, Hg/TSS) at the USGS gauge during pre-mining conditions. Concentrations of mercury in suspended sediment vary with flow regime and season (Section 2.3.4). These variations occur because the sources in Sulphur Creek are heterogeneous in terms of concentrations and forms of mercury and suspended sediment. Geothermal spring fluids, geothermal precipitates, and material eroded from various mine features have different concentrations of mercury and TSS, which are not completely integrated by the time the flow exits Sulphur Creek.

Given the variation in Hg/TSS concentrations, it may be possible to identify a monitoring strategy by which the effectiveness of remediations could be readily identified. As shown by the data collected by an autosampler through a storm (Figure 2.4), the initial runoff is associated with a sharp peak in the Hg/TSS ratio. This peak likely represents mobilization of geothermal precipitates. The Hg/TSS ratio then declines to a fairly consistent level (average 6.0 mg/kg, range 4.2-8.7 mg/kg) throughout the storm. The bulk of suspended sediment transported during high flow likely comes from mercury mine waste and contaminated stream banks. As these sources are controlled, Regional Board staff anticipates that the Hg/TSS ratio collected in the latter part of a storm will be significantly lower than existing conditions. The load allocations (Table 5.1) indicate that controlling sources affected by anthropogenic activity will decrease mercury loads by 70%. A similar decline in concentrations of mercury in suspended sediment would put the Hg/TSS ratio during the peak of a storm at 1-3 mg/kg.

3.4 Numeric Target Summary

The TMDL numeric target is 0.2 mg/kg (dry weight) for mercury in fine-grained sediment. The target is based on natural, background levels of mercury in the Sulphur Creek watershed. A preliminary cleanup goal for mercury in soil transported off of the mine areas is 3 mg/kg. This cleanup goal may be refined for individual mine sites if more specific data are gathered.

4 LINKAGE ANALYSIS

The goals of the Sulphur Creek Mercury TMDL are to reduce mercury loads coming from anthropogenic activities in the watershed and to reduce inorganic and methylmercury loads exported to Bear Creek from Sulphur Creek. The main purpose of the linkage analysis is to describe the relationship between inorganic mercury and methylmercury.

Quantitative links between inorganic mercury and methylmercury in water, and between water and sediment concentrations cannot be made with available data. Total mercury load reductions in Sulphur Creek are needed to reach pre-mining conditions in non-mineralized (target of 0.2 mg/kg in sediment) and mineralized zones (preliminary goal of 3 mg/kg in sediment). Regional Board staff expects that reducing total mercury loads will reduce mercury sediment concentrations and result in a methylmercury load reduction. Methylmercury production in sediment is the critical first step in a complicated process that culminates in elevated levels of methylmercury in water and biota.

4.1 Methylmercury Production

Methylmercury concentrations are the result of two competing processes, methylation and demethylation, neither of which is well understood. Methylation is the addition of a methyl group to an inorganic mercury molecule (Hg^{+2}). Sulfate reducing bacteria are the primary agents responsible for the methylation of mercury in aquatic ecosystems (Compeau and Bartha, 1985; Gilmour *et al.*, 1992). Maximum methylmercury production occurs at the oxic-anoxic boundary in sediment, usually several centimeters below the surface. Methylmercury fluxes from the sediment to the overlying anaerobic water and mercury becomes available to the biotic community when contaminated bottom water is mixed into the overlying water column. The fact that methylmercury is always measurable in Sulphur Creek implies that the rate of methylation is greater than demethylation.

Factors controlling methylmercury production in sediment have been the subject of intense scientific research. (For reviews see Wiener *et al.*, 2003 and Benoit *et al.*, 2003.) Sediment factors and landscape events important in net methylmercury production include the percent organic content of the sediment (Krabbenhoft *et al.*, 1999; Miskimmin *et al.*, 1992; Hurley *et al.*, 1998; Heim *et al.*, 2004; Slotton *et al.*, 2004b), pH and sulfate concentration of the overlying water (Gilmour *et al.*, 1998; Miskimmin *et al.*, 1992; Krabbenhoft *et al.*, 1999), creation of new water impoundments (Verdon *et al.*, 1991; Bodaly *et al.*, 1997), and the amount and kind of inorganic mercury present in the sediment (Krabbenhoft *et al.*, 1999; Bloom, 2004). Neither the organic content of the sediment or pH of the overlying water appears controllable in the Sulphur Creek watershed and are not discussed further.

4.1.1 Sulfate in the Mercury Cycle

Streams associated with mercury mine drainage, such as Sulphur Creek, have elevated sulfate concentrations (Rytuba, 2000). The combination of high mercury and sulfate concentrations in water provides an ideal environment for sulfate-reducing bacteria to methylate mercury. Additions of sulfate to sediment have been observed to both stimulate (Gilmour *et al.*, 1992; King *et al.*, 2002) and inhibit **(**Benoit *et al.*, 1999a; Gilmour *et al.*, 1998) methylmercury production, depending on sulfate concentrations and sulfate/sulfide ratio. Sulfate promotes mercury methylation within mine wastes as well as where the mine drainage meets the stream water (Rytuba, 2000). Rytuba (2000) suggests that diverting water from mine waste will decrease methylation within the mine wastes and minimize mercury and methylmercury runoff.

4.1.2 Sediment Mercury Concentrations

The production of methylmercury in sediment has been found to be a function of the total mercury content of the sediment. Heim and colleagues (2004) report a weak positive correlation between methylmercury and total mercury in sediment ($r^2 = 0.19$, $n = 99$, and $p<0.01$) across the Sacramento-San Joaquin River Delta. The correlations improve markedly when data are plotted by habitat type (e.g., stream, wetland, or open water). Other studies cited in the Cache Creek Mercury TMDL detail statistically significant, positive relationships of methylmercury to total mercury in sediment (Krabbenhoft *et al.*, 1999; See also CVRWQCB, 2004). In laboratory studies in which mercury was added to sediment and subsequent methylmercury production was measured, the efficiency of conversion of mercury to methylmercury was linear before approaching the asymptote or declining (Bloom, 1994; Rudd *et al*., 1983). The slope of the line decreased when sediment mercury concentrations were greater than 1-10 mg/kg. These results suggest that control programs that are able to successfully reduce total surficial sediment mercury concentration will also reduce the production and flux of methylmercury to the overlying water. Much greater reductions in total mercury may be required to achieve similar reductions in aqueous methylmercury when sediment concentrations exceed one mg/kg total mercury.

4.1.3 Mercury Forms

Mercury present at Sulphur Creek mine sites is predominantly in mercury sulfide (cinnabar) form (Churchill and Clinkenbeard, 2004). Cinnabar is believed to be the least soluble and most inert of the mercury species. Sediment samples from Cache Creek containing cinnabar were mixed with sediment from Green Lake[7] and incubated in the laboratory for a year to ascertain its methylation potential. Mercury mine waste was about 20 times less efficiently converted to methylmercury than was dissolved mercury^{2+}, the most available form of mercury (Bloom, 2004). However, mine waste, in spite of its low conversion efficiency, produced large amounts of methylmercury in the laboratory because of its high total mercury content.

[7] Green Lake is near Frontier GeoSciences in Seattle, Washington.

The ratio of methyl to total mercury in bulk surficial sediment is assumed to be a field measure of methylation efficiency (Gilmour *et al.*, 1998; Krabbenhoft *et al.*, 1999; Bloom *et al.*, 1999; Bloom, 2004). Heim and others (2004) collected sediment samples from sites in the Cache Creek watershed on three occasions (October 1999, May 2001 and October 2001) to measure methyl and total mercury concentrations and determine methylation efficiency. The highest total mercury concentrations were observed in sediment from Harley Gulch and Sulphur Creek. Sediment methylmercury concentrations were also very elevated at these same locations. However, consistent with the findings of Bloom (2004), methylation efficiency was low. This may be because of the high total mercury concentration (see previous section on the effect of total mercury on methylmercury production) and/or because the material is still mostly insoluble cinnabar.

4.2 Mercury Mobilization by Mine Drainage

Water flowing through adits, waste rock and tailings piles can solubilize and increase the transport of mercury, beyond the inputs from erosion of mercury-containing soil and rock particles. Water flowing through the mine workings and rock piles, termed mine drainage, can be geothermal in origin or a combination of geothermal, freshwater spring, and infiltrated rainfall. Both mercury and methylmercury occur in low to moderate concentrations within mine drainage (Rytuba, 2000). Elevated concentrations of sulfate associated with mercury mine drainage promote methylmercury production within the drainage as well as in the receiving water.

As water exits mine workings, the drainage flows through calcines and waste rock where it dissolves more soluble mercury (Rytuba, 2000). Mercury and methylmercury concentrations increase as water flows through mine waste and calcined material that was usually dumped close to mine workings. In the Sulphur Creek watershed, mine drainage has been observed at the Elgin site.

When drainage from mine workings enters the stream, the reaction with oxygen and iron causes iron oxyhydroxide to precipitate, allowing mercury and methylmercury to adsorb to the particulate matter (Rytuba, 2000). Rytuba (2000) reports that the dissolved fractions of both mercury and methylmercury decrease downstream from mine sites and that movement of mercury is mostly in the particulate phase. Iron oxyhydroxides accumulate in instream sediment during low flow summer months and are disturbed and redeposited downstream during storm events.

4.3 Mercury Control Programs

Mercury control programs in other water bodies have emphasized a combination of decreasing/eliminating mercury loads and natural burial of contaminated sediment. Decreasing or eliminating mercury loads is usually the first control measure undertaken. This is critical as it begins to reduce sediment mercury levels and the stock of new mercury to be methylated. Dredging and removal of contaminated sediment or capping with clean material has been employed less often than natural burial; presumably this is because of cost (Rudd *et al.*, 1983; Francesconi *et al.*, 1997).

Mercury concentrations in fish at contaminated industrial sites decline after control measures are instituted to reduce incoming mercury loads. The initial decrease in fish tissue concentration near the contamination source is often fast, with about a 50 percent decline in the first five to ten years. However, after a rapid initial decrease, concentrations tend to stabilize with little, if any, subsequent decline (Turner and Southworth, 1999; Takizawa, 2000; Lodenius, 1991; Lindestrom, 2001; Francesconi *et al*., 1997).

No published reports were found on remediation of pollution from mercury mining. The long duration of mining in the Sulphur Creek watershed coupled with the extensive distribution of contamination may make recovery slower than at industrial sites. Proposed control measures for Sulphur Creek are similar to what have been employed in other mercury-contaminated watersheds. In addition, scientists at institutions separate from the Regional Board have proposed studies to evaluate whether it is possible to interrupt the microbial methylation cycle Improvements in methylmercury control measures will be reviewed by Regional Board staff and incorporated into the implementation plan.

4.4 Linkage Analysis Summary

Studies have shown statistically significant linear relationships between methyl and total mercury where methylmercury in sediment is a function of its total mercury content. Significant total mercury loads enter Sulphur Creek, which result in increased instream methylmercury production. As a result, Sulphur Creek exports considerable loads of mercury and methylmercury to Bear Creek. Reducing total mercury loads from identified sources will lead to reduced methylmercury loads in Sulphur and Bear creeks. Proposed mercury control measures for the Sulphur Creek watershed to reduce/eliminate discharge from mine sites, contaminated stream banks, and other inputs are similar to those that have been employed elsewhere. Possible implementation activities for Sulphur Creek are discussed further in Section 7.

5 LOAD ALLOCATIONS

As described in the linkage analysis, reductions in total mercury loads are needed to restore the watershed to conditions prior to mining. Reductions in total mercury loads from Sulphur Creek are also needed to reduce loads of mercury and methylmercury in Bear Creek. The first part of this section describes Regional Board staff's estimate of mercury loads by source types, based on details in the Source Analysis. The second part delineates load allocations of total mercury.

Note on the May 2006 Final Report: The draft Sulphur Creek TMDL report was released in August 2004. The draft report contained a draft allocation of total mercury loads (Table 5.1). In October 2005, the Central Valley Water Board adopted the Basin Plan Amendment for Control of Mercury in the Cache Creek Watershed (CVRWQCB, 2005). The Basin Plan Amendment contained methylmercury load allocations for tributaries and stream reaches and total mercury load allocations for mine sites. After the Basin Plan Amendment was adopted, staff revised Table 5.1 and accompanying text to be consistent with the Board-approved implementation plan.

5.1 Assessment of Mercury Loads by Source Type

Regional Board staff combined the tributary budget (Table 2.2) with estimates of geothermal and erosion inputs to develop an estimate of mercury loads as divided by source types. This source type and tributary budget is provided in Table 5.1. An analysis by source type is useful for allocating loads between the various sources. The source types evaluated are mines/mineralized areas on tributaries, geothermal springs, erosion of non-mineralized soil, mine areas and associated contaminated streambed, and atmospheric deposition[8].

The average annual mercury load from outside of the named mine sites is assumed to be 1.2 kg/year. This assumption applies at least to water years with average flows and/or storm events. Following extreme erosion events or flooding, loads from these areas would be higher. The estimate is based on the low estimate of runoff load by Churchill and Clinkenbeard (2004; See Section 2.3.2), which was 0.9 kg/year. The non-mine sites erosion estimate includes 0.3 kg/yr[9] of the load estimated for the upper watershed, which may originate from resuspension of contaminated stream bed sediment downstream of Elgin or East Branch mine sites or geothermal springs that have not been monitored.

Contributions from the mine areas on measured tributaries, Clyde, Elgin and Wide Awake, are taken directly from Table 2.2. Although each tributary drains a small watershed as well as the mine site, most of the loads are thought to originate from the mine sites. Mercury loads from the Elgin site likely derive from a combination of erosion of mine waste, geothermal springs, and

[8] No new load data are provided in Section 5.1. Section 2 presents mercury load estimates that are based on concentration data collected downstream of identifiable inputs and at tributary mouths. In Section 5.1, these load estimates are regrouped and presented based on major source at these input sites.

[9] 1.2 kg/yr (Table 2.2) – 0.9 kg/yr.

interaction of geothermal water as it flows through the mine workings and waste piles. The extent of the mineralized zone at Elgin is unknown. Stream sediment samples collected between the top of the ridge above Elgin and the uppermost of the water collection sites at Elgin, however, showed a significant decrease in sediment mercury concentrations with distance upstream, away from the mine site. The tributary upstream of Wide Awake Mine has not been sampled. Presumably as for the Clyde and Elgin sites, most of the mercury load from the Wide Awake tributary originates from the Wide Awake mine site.

Mercury loads measured instream above and below mines in the lower Sulphur Creek watershed were shown in Table 2.2. Mercury sources in these stretches include erosion of contaminated stream bed, banks and floodplain, erosion from waste piles and other mine features above the floodplain, and geothermal springs. The geothermal estimate from Section 2.3.5 (1.4 kg/year) is shown separately in Table 5.1. This geothermal input is subtracted from the mine-related load estimate for the lower watershed. It is not possible to separate the loads from "new" inputs from the terrestrial portions of the mine sites from floodplain and stream bed inputs. Operations at West End, Cherry Hill, Central, Empire and Manzanita mine sites resulted in ore, tailings and/or waste rock being deposited within the Sulphur Creek floodplain (Churchill and Clinkenbeard, 2004; Tetra Tech, 2004). Mercury eroding from mine features above the floodplain may be redeposited below and take more than one year to reach the creek (Churchill and Clinkenbeard, 2004). Because of the deposition and remobilization, it may not be necessary to separate these loads further for remediation purposes. The lower watershed mine (except Wide Awake) and stream bed load estimate in Table 5.1 was calculated by adding the load estimates from Table 2.2 measured downstream of West End, Manzanita, Central and Empire mines and Wilbur Springs and subtracting the estimate for lower watershed geothermal loads.

Atmospheric deposition of mercury, both directly to the creek surface and indirectly to the rest of the watershed with transport in runoff, contributes an estimated 0.03 kg/yr to mercury loads at the USGS gauge. The atmospheric load is far smaller than estimates from other source types.

5.2 Allocations for Total Mercury Loads

Allocations of mercury loads are shown in Table 5.1. Allocations are based on the goal of eliminating inputs of mercury caused by anthropogenic activities, particularly mining. The allocations are presented as a percentage of existing loads. Loads are expected to fluctuate with the magnitudes of precipitation events and flow. Current and future load estimates for average water years are also provided.

In general, geothermal springs are considered natural (background) sources of mercury and are not assigned a load reduction. Geothermal springs in the lower watershed (Wilbur, Jones Fountain, Blanck, Elbow and other unnamed springs) are assigned no load reduction. An exception is the springs at Elgin Mine that flow over mine waste before entering the West Fork Sulphur Creek. Historically, spring water flowed through the Elgin mine tunnels (Churchill and Clinkenbeard, 2004). Spring water (possibly a combination of geothermal fluid and infiltrating rainwater) reacts with the waste rock within the tunnels and on the slope below, increasing the waterborne concentrations of mercury and sulfate (Rytuba, 2000). Remediation at the Elgin site to meet the load reductions is expected to require at least partial treatment of the effect of spring flows on the mobilization of mercury. Tetra Tech (2004) has evaluated treatment options for the Elgin springs.

The sum of mercury loads from areas outside of the named mine sites is allocated 60% of existing loads. Erosion of undisturbed soil is considered a natural source of mercury. Thus loads from undisturbed areas are not expected to be reduced. It is also likely, however, that areas outside of the named mine sites contain mine waste that has been transported by erosion. This may be particularly true in the East Branch Sulphur Creek, where instream sediment concentrations of mercury were relatively high (Figure 2.2). Erosion from the watershed outside of the named mine sites may be exacerbated by grazing, road cuts or other anthropogenic activities. To adequately control mercury levels in the watershed, loads from the anthropogenic impacts of mine waste and increased erosion should be reduced. Further investigations are needed of stream bank deposits and inputs, particularly in the East Branch.

Table 5.1 Sulphur Creek Total Mercury Budget by Source Type and Load Allocations

Source	Current Load, kg/yr (a)	**Load Allocation** as percent of existing loads (b)	Future Load, based on current load estimates, kg/yr
Geothermal springs	1.4	100%	1.4
Non-mine site erosion	1.2	60%	0.5
Clyde Mine	0.4	5%	0.02
Elgin Mine	2.7	5%	0.13
Wide Awake Mine	0.8	5%	0.04
Lower Watershed Mines plus contaminated stream bed	5.3	15%	0.8
Atmospheric Deposition	0.03	100%	0.03
Sum	11.8	25%	2.9

(c) Based on estimates from data collected in 2000-2004.
(d) Load allocations are expressed as a percentage of existing loads. For average water years, a comparison between current and future loads is given.

The allocation for atmospheric deposition is unchanged from existing loads. Deposition from the atmosphere is minimal, relative to other loads in the watershed. Reducing mercury in the global atmospheric pool is beyond the scope of this TMDL. It is anticipated that remediation of the mine sites will reduce atmospheric inputs from local and regional sources, but no estimates are available.

The total load allocation (Table 5.1) for the lower watershed mines and mine-related material in the streambed and banks is 15% of existing loads. In the lower watershed area between West End and Central Mines, mercury originating on the mine sites has not been differentiated from mercury mobilized from the stream bed and banks contaminated by mine operations. These mine-related tributary and lower watershed allocations in Table 5.1 take into account mercury from undisturbed, mineralized and non-mineralized soil in the mine sub-watersheds as well as from the mines.

Although tributaries and the stream bed below the mine sites are allocated 10-15% of existing loads, the goal for the terrestrial mine sites is to eliminate all mercury inputs affected by mining. **The load allocation assigned to each mine site is 5% of existing loads of total mercury**[10]. These sites are: Clyde, Elgin, West End, Manzanita, Central, Empire, Cherry Hill, and Wide Awake Mines. The allocation to the mines is to ensure that inputs from the mines are reduced, within limits of technical achievement, to pre-mining conditions. The mine allocation applies to waste rock, tailings and ore piles, soil under processing sites, processing facilities and equipment, and other features impacted by mine operations. If geothermal waters interact with mine waste, as at Elgin, a more detailed analysis may be required to determine the mercury contribution from the geothermal spring alone.

Alterations to geothermal springs in the watershed must not increase loads of mercury or methylmercury entering Sulphur Creek. This cap on existing loads applies to the Wilbur Hot Springs resort and any other future geothermal development, modifications or treatment operations.

5.3 Methylmercury Loads

As described in the linkage analysis, methylmercury loads are closely correlated with total mercury loads. The allocation described above is also intended to reduce loads of methylmercury in Sulphur and Bear Creeks. As described in the Cache Creek, Bear Creek and Harley Gulch TMDL for Mercury, loads of methylmercury from Sulphur Creek should ultimately be reduced to about 10% of existing loads in order to attain the goals for Bear Creek (CVRWQCB, 2005). Implementation of both of the Bear Creek and Sulphur Creek TMDLs will occur in a phased process. In the first phases of implementation, the primary method for achieving the methylmercury reductions will be to reduce total mercury loads within and entering Bear Creek and Sulphur Creek. In the second phases, additional information regarding control of other factors that affect methylmercury production will be evaluated and incorporated into the implementation plans as feasible. Treatment of geothermal springs in Sulphur Creek would likely cause additional reduction in methylmercury loads from Sulphur Creek. After major remediation efforts, Bear Creek and Sulphur Creek will be monitored to ensure that total mercury and methylmercury levels have adequately declined.

[10] As long as West End, Manzanita, Central, Empire, and Cherry Hill mines are owned by the same entity, the 95% allocation may be applied to the total input from these five sites. Rathburn, Rathburn-Petray, North Petray and South Petray Mines are addressed in the Bear Creek TMDL for Mercury.

6 MARGIN OF SAFETY AND SEASONAL VARIABILITY

6.1 Margin of Safety

The margin of safety is implicit in the load allocations for total mercury. The goal of this TMDL is to eliminate mercury inputs that resulted from mining, grazing, road development, and other human actions. Load estimates and allocations were separated on whether the mercury derived from background conditions or were exacerbated by anthropogenic activity. Implementation of this TMDL should restore Sulphur Creek to its natural condition with respect to mercury. Additional water quality benefits will likely be attained through reductions in loads of sulfate that originate from the same sources as mercury. Beyond eliminating the mercury loads related to anthropogenic activities, no additional margin of safety is necessary.

6.2 Seasonal Variability

Seasonal variability in total and methylmercury loads was accounted for in the source analysis and load allocations. Loads of mercury and methylmercury in Sulphur Creek fluctuates with the seasons. Average, annual loads of total mercury and methylmercury were estimated using data collected throughout the year to account for the seasonal changes in transport of total mercury and methylmercury and methylmercury production. Winter precipitation increases the aqueous concentrations of sediment and total mercury entering the creeks through erosion and resuspension of sediment. Because flows are greatest during the storm season, total mercury and sediment loads (concentration X flow) are greatest in winter. Most of the total mercury enters Sulphur Creek during high flow events.

Like total mercury, loads of methylmercury are greatest in winter. In contrast to total mercury concentrations, however, concentrations of methylmercury are not closely associated with runoff and flow. Methylmercury production is typically higher during the summer. Aqueous methylmercury concentrations show peaks in early summer, when *in situ* production is greatest, and after the first storms, when methylmercury produced in the tributaries is flushed downstream (Figure 6.1; Slotton *et al.*, 2004a). Seasonal methylmercury concentrations in benthic invertebrates exhibit a pattern similar to that of the water (Slotton *et al*, 2004a).

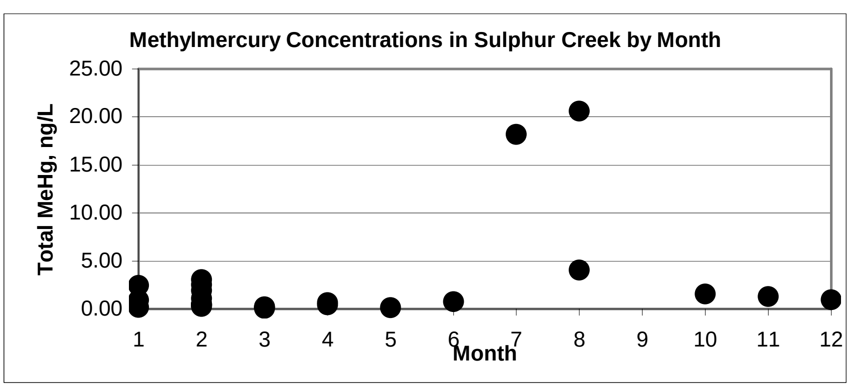

Figure 6.1 Aqueous Methylmercury Fluctuations by Month at the Sulphur Creek Gauge. Sources: Slotton *et al.*, 2004a and unpublished data collected by Regional Board Staff.

7 IMPLEMENTATION PLAN

The following is a preliminary plan for a mercury load reduction program for Sulphur Creek. The implementation plan may consist of multiple projects, some of which are discussed here. Various projects and alternatives will be evaluated during the Basin Plan amendment development process to implement the TMDL. The alternative projects and compliance time schedules will be evaluated in accordance with the Porter-Cologne Water Quality Act, Section 13242.

The Sulphur Creek TMDL implementation plan will be incorporated into the Cache Creek Basin Planning process (The Cache Creek TMDL technical report was completed in February 2004 and is available on the Regional Board's website). The final implementation strategy for the Sulphur Creek TMDL will be determined based on the implementation plan adopted by the Regional Board through a Basin Plan amendment, tentatively scheduled for Region Board consideration in Summer 2005.

The goals of the implementation plan will be to reduce the mercury concentration in sediment within Sulphur Creek and to reduce the overall mercury loading to Bear Creek. To achieve these goals, staff will propose a program that could include these major components:

1) Reduce total mercury discharges from the mercury mine sites;
2) Reduce the concentration of mercury in Sulphur Creek sediment adjacent to and downstream of the mercury mines;
3) Control erosion of contaminated sediments within the Sulphur Creek watershed where the total mercury sediment concentrations are greater than 0.2 mg/kg, dry weight; and
4) Evaluate the feasibility of controlling mercury loads from geothermal springs.

The TMDL implementation program could begin by starting the process for remediation of inactive mercury mines to limit output of mercury. After mine remediation, there may be opportunities to remediate the Sulphur Creek streambed to reduce mercury in sediment. Staff will evaluate options for erosion control, stream bank stabilization, sediment removal, and allowing sediment with low concentrations of mercury to replace or bury contaminated material in the streambed.

Table 7.1 provides an outline of the sources of mercury and potential implementation options for this TMDL. The public and private stakeholders are also indicated. Text following the table describes the implementation actions in greater detail. Table 7.1 separates the mercury mines by current ownership (See Load Allocations section).

The load reduction program could evaluate controlling mercury discharges from mine sites and reducing of non-point sources of mercury. Reducing loads of mercury from the tributaries could focus on identifying upstream sources of mercury and, if possible, controlling releases from them. Sites could be prioritized by their mercury/TSS ratio, total loads, or vicinity to inputs upstream of wetlands or other sites with high methylmercury production rates. At this time, no sources other than the mercury mines identified in Table 7.1 have been identified. There may be "hot spots" of mercury loading within the smaller tributaries that could be reduced. Regional Board staff may continue sampling efforts to identify potential hot spots of mercury loading.

Regional Board staff could recommend that the various agencies coordinate efforts to develop and implement monitoring and restoration programs. Regional Board staff may work with the agencies to evaluate funding opportunities.

Table 7.1 Potential Implementation Options for Reducing Mercury in Sulphur Creek

Mercury Source	Potential Implementation Options	Public and Private Stakeholders
Central, Cherry Hill, Empire, Manzanita, and West End mines	Waste discharge requirements or enforcement orders for inactive mine sites; evaluate control of erosion in the stream banks downstream of the mines; evaluate BMPs[a] to reduce erosion and effects of grazing.	Private Landowners and/or responsible parties
Clyde, Rathburn, and Rathburn-Petray mines[b]	Waste discharge requirements or enforcement orders for inactive mine sites; evaluate control of erosion in the stream banks downstream of the mines; evaluate BMPs to reduce erosion and effects of grazing.	USBLM
Elgin Mine	Waste discharge requirements or enforcement orders for inactive mine sites; evaluate control erosion in the stream banks downstream of the mines; evaluate BMPs to reduce erosion and effects of grazing.	Private Landowners and/or responsible parties
Wide-Awake Mine	Waste discharge requirements or enforcement orders for inactive mine sites; evaluate control of erosion in the stream banks downstream of the mines; evaluate BMPs to reduce erosion and effects of grazing.	Private Landowners and/or responsible parties
Geothermal Springs	Evaluate the feasibility of controlling mercury loads from geothermal springs.	USBLM, Colusa County, Private Landowners
Wilbur Hot Springs	Evaluate the feasibility of controlling mercury loads from geothermal springs.	Private Landowners
Sulphur Creek Streambed	Evaluate BMPs for erosion control; evaluate control for bank stabilization, revegetation, and contaminated sediment removal.	USBLM, Private Landowners
Background Mercury Loads (non-anthropogenic) in Watershed	Evaluate BMPs to reduce erosion of soil with more than 0.2 mg/kg mercury. Investigate and control hot spots in tributaries. Possibly evaluate BMPs to reduce erosion and effects of grazing; stream bank stabilization.	USBLM, Colusa County, Private Landowners
Deposition of Mercury from the Global Atmospheric Pool	No change from existing loads (local atmospheric deposition may decrease with mine waste remediation).	None

(a) BMPs- Best management practices.
(b) Mercury from the existing mine waste piles and pits on the Rathburn-Petray and Rathburn sites is thought to discharge to tributaries of Bear Creek (Churchill and Clinkenbeard, 2004; Tetra Tech, 2004). Because some activities on these properties, such as road cuts, operations prior to open pit mining, or other prospects, may contribute mercury to Sulphur Creek, Rathburn-Petray and Rathburn Mines are listed here.

7.1 Mercury Mines

The TMDL implementation plan for the Sulphur Creek TMDL could include a schedule for adopting waste discharge requirements or enforcement orders (e.g., NPDES permits, Title 27 requirements, storm water permits, or cleanup and abatement orders) for the mercury mine sites to control discharges. The permits could include requirements that the mine owners develop and implement mine remediation plans to control discharges of mine wastes. The plans could evaluate pre-mining concentrations within the mineralized zone and determine local soil background or cleanup levels. The mine remediation may be accomplished through a variety of engineering actions including, but not limited to, surface water diversion, erosion control, landslide stabilization, regrading, waste pile containment, capping, relocation or removal, and revegetation. Cost-effective remediation of the mine sites will likely include excavation of highly-contaminated processing site soil, waste rock or tailings and surface water controls to reduce erosion of the regraded sites (Tetra Tech, 2004). Capping with a liner and clean soil and revegetation may also be warranted.

Engineering feasibility studies have been conducted for remediating the mines listed in Table 7.1 to reduce off-site movement of mercury (Tetra Tech, 2004). The results of the feasibility studies will be considered in the evaluation of alternatives for the Sulphur Creek mines.

Regional Board staff estimated the improvements that can be made by remediation of the mine sites. As described in Section 2.3.2, Churchill and Clinkenbeard (2004) estimated current mercury loads from waste rock, tailings, and other mine features using probable erosion rates and existing mercury concentrations[11]. Regional Board staff repeated this exercise, assuming a mercury concentration in enriched soil of 3 mg/kg and the minimum and maximum erosions rates proposed for each mine feature by Churchill and Clinkenbeard (2004)[12]. Although Regional Board staff used the estimate of current erosion rates from the mine waste and tailings piles, post-remediation rates would likely be much lower due to routing of surface water around the features and other surface water controls. Regional Board staff estimates that remediation of the mine sites could reduce annual mercury delivery from the Sulphur Creek sites to 0.09-0.3 kg/year, which is a 92-98% reduction from current delivery estimates (See Table 2.3 for comparison).

[11] Details on the area, erosion estimates and mercury levels of mine features can be found in Appendix N of the report by Churchill and Clinkenbeard (2004). http://loer.tamug.tamu.edu/calfed/FinalReports.htm

[12] Example estimate of annual delivery of mercury from the grass-covered waste rock pile on the Empire mine site (Churchill and Clinkenbeard, 2004): Area of waste rock pile is 0.68 acres. Estimated erosion rates using the Revised Universal Soil Loss Equation 2 (RULSE2) from this waste pile is 0.46-0.61 tons per acre per year. Average, existing mercury concentration in waste pile is 150 mg mercury/kg soil.

a) Minimum annual soil loss = 0.68 acres * 0.46 tons/acre-yr = 0.31 tons soil /year.

b) Minimum annual Hg loss = 0.31 tons soil/yr * 150 mg Hg/kg soil * convert from tons to kg = 0.04 kg Hg/year.

Substituting a mercury concentration of mg/kg in equation (b) results in a post-remediation minimum estimate of loads from the Empire mine site pile of 0.0009 kg Hg/year (Using the maximum erosion rate instead of minimum erosion rate results in an estimated future mercury load of 0.0012 kg/year).

7.2 Contaminated Instream and Bank Sediments

As described in the source analysis, mercury contaminated sediments instream and along the bank originated primarily from mercury mines and to a lesser extent from background and naturally enriched areas. It is expected that even after the mercury mines are remediated, contaminated sediment will be present in the streambed for a long time unless actions are developed and implemented to expedite mercury removal. A potential load allocation program for the creek could be to 1) identify erosive creek sections with elevated mercury in the sediment, and 2) evaluate options to reduce erosion or remove the contaminated sediments. Attainment of the load allocation to the Upper Watershed area may require reducing the impacts of cattle grazing, stabilization of streambeds, and treatment of any “hot spots” that are identified.

Regional Board staff may coordinate with the Bureau of Land Management and local, state and federal land management agencies and Colusa County to address erosion control and mercury hot spots, to review and update watershed management plans, to update plans to minimize erosion of mercury-contaminated soils, and to consider a grazing moratorium in erosion sensitive-mercury enriched areas. These efforts might include a review of grazing and land development policies that effect soil erosion. Additional BMPs could be implemented in areas where soil erosion is a problem.

The TMDL implementation plan may recommend that ecosystem restoration or preservation projects focus on erosion control in areas with elevated sediment mercury levels. It is possible that there may be projects to remove invasive vegetation along Sulphur Creek. For TMDL implementation, Regional Board staff could recommend that proponents monitor stream bank stabilization projects and implement erosion control projects during the restoration program.

Coupled with diverting water around contaminated mine site material, as mentioned in the previous section, Tetra Tech (2004) suggested the use of instream retention basins to trap contaminated sediments. Sediment transported downstream during storm events would be settled out in the detention structure. The trap could then be cleaned out and contaminated sediments could be moved off-site and buried.

Roads within the watershed are limited; the main road along Sulphur Creek is unpaved and infrequently maintained. There are other un-maintained four-wheel drive roads that have limited use but are potentially susceptible to erosion. Staff may recommend that road improvement or maintenance projects propose and implement additional erosion controls.

7.3 Geothermal Sources

In general, geothermal springs that discharge mercury and sulfate are naturally occurring and may not be controllable discharges. Some geothermal inputs may have been aggravated by mining operations, as active mining had affected geothermal spring discharges (Churchill and Clinkenbeard, 2004; Tetra Tech, 2004). Because geothermal fluids can increase the flux of mercury from mine waste and contaminated sediment (Rytuba, 2000), control of the fluid output may be effective in reducing mercury loads in Sulphur Creek. It is possible that geothermal discharges are potential candidates for remediation or mercury offset projects. Landowners with active geothermal springs may be required to do a feasibility study to determine potential load reductions.

The Wilbur Hot Springs resort is a source of mercury to Sulphur Creek. Regional Board staff may recommend that any development or alteration of geothermal springs in the watershed should result in no net increase in methylmercury or mercury loads in Sulphur Creek. If the Wilbur Hot Springs resort or other entity wishes to develop geothermal springs or engage in other activities that are predicted to increase the net mercury or methylmercury loads, the Regional Board may decide to allow the discharger the option of participating in offset program. The offset program may require that the discharger reduce the load from a source elsewhere in Sulphur Creek to compensate for the increase due to development.

7.4 Atmospheric Inputs

The allocation for atmospheric deposition is capped at the maximum mercury load estimated to accumulate from the global atmospheric pool, which is 0.03 kg/year. Atmospheric mercury originating outside of the watershed is considered an uncontrollable source under this TMDL. As noted in the source analysis, atmospheric loads of mercury derive from global, regional, and local sources. Mercury from Sulphur Bank Mercury Mine is a regional atmospheric source that may deposits locally in the Sulphur Creek watershed. Local mercury flux from Sulphur Bank will be controlled by USEPA Superfund remediation activities at the mine site; therefore, there should be slightly less atmospheric loading from local sources after remediation.

8 PUBLIC PARTICIPATION

Regional Board staff received data and background information for this report from the USEPA, USFWS, USGS, US Bureau of Reclamation, California Department of Fish and Game, California Department of Water Resources, California Department of Conservation, California Bay Delta Authority, and Tetra Tech EM Inc. Stakeholder comments were received at a public workshop and CEQA (California Environmental Quality Act) Scoping Meeting for mercury in the Cache Creek watershed. The public workshop was held in Woodland, CA on 4 June 2004.

Staff solicited further public participation in development of this report by:

- Sending notification of availability of the draft TMDL Report to interested parties (e.g., federal, state and local agencies involved in the watershed, private landowners, members of the Cache Creek Stakeholders Group and any other local watershed groups, the Delta Tributaries Mercury Council (DTMC) and other interested groups and persons). The draft TMDL report and appendices will be available in PDF format on the Central Valley Water Board's website: http://www.waterboards.ca.gov/centralvalley/programs/tmdl/Cache-SulphurCreek/index.html. Paper copies of the report were sent to interested persons upon request.
- Soliciting and reviewing the public's written and verbal comments. Staff met with private landowners of potentially affected mine properties in April 2005
- Obtaining comments on the Sulphur Creek TMDL and implementation plan during the Basin Planning Process for mercury in the Cache Creek watershed. For the Cache Creek watershed mercury Basin Plan Amendment, staff held a workshop before the Central Valley Water Board on 18 March 2005 and public hearings on 23 June and 21 October 2005. Written responses to comments received at the workshop and hearings are available on the Central Valley Water Board's website.
- Continuing to coordinate with and receive input from the DTMC. Monitoring and implementation activities of this TMDL fit within recommendations of the DTMC's Strategic Plan for the Reduction of Mercury Related Risk in the Sacramento River Watershed (DTMC Strategic Plan[13]). Specifically, the DTMC Strategic Plan recommends monitoring soil samples in tributary watersheds with higher than average Hg/TSS, additional sediment and water monitoring to quantify mercury loads, planning of remediation projects that may serve as pilot projects for the Sacramento River Watershed, and development and implementation of public outreach.

[13] The DTMC Strategic Plan is available: http://www.sacriver.org/subcommittees/index.php?action=ShowNode&subcommittee=dtmc

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APPENDIX A. FLOW DATA

The USGS operates one flow gauge on Sulphur Creek, about one mile upstream of the mouth. Data for this gauge can be accessed on the following website: http://nwis.waterdata.usgs.gov/ca (Site Code = 11451690). Summary flow data for the gauge are presented in Table 2.1 of the Source Analysis. Continuous flow data are not available for other parts of the watershed. In order to estimate mercury loads from all areas, flow was estimated at each sampling site based on the relative size of the drainage area to the drainage area at the gauge. Flow records at the stream gauge and estimated flow are presented in Table A.1. Daily average flow graphs in Figure A.1 show annual flow patterns in Sulphur Creek over the four years of record.

Table A.1 Estimated Flow at Sampling Sites Based Relative Area to USGS Stream Gauge Recorded Data

Site	Area (miles^2)	Percentage of Area to Gauge	Water Year Flow (acre-feet/year)			
			2000	2001	2002	2003
SC-01 (USGS Stream Gauge)	10.1		2254	1439	2839	3307
SC-08	9.9	98%	2209	1410	2782	3240
SC-09	0.39	4%	88	56	111	129
SC-03	8.8	87%	1963	1253	2473	2880
SC-04	0.45	5%	106	68	133	155
SC-05	0.06	0.6%	14	9	17	20
SC-06	8.4	83%	1875	1197	2362	2751
SC-07	8	79%	1785	1140	2248	2619
SC-23	0.73	7%	162	104	204	238
SC-22	0.59	6%	131	83	165	192
SC-20	0.27	3%	61	39	77	89
SC-21	0.47	5%	106	68	133	155

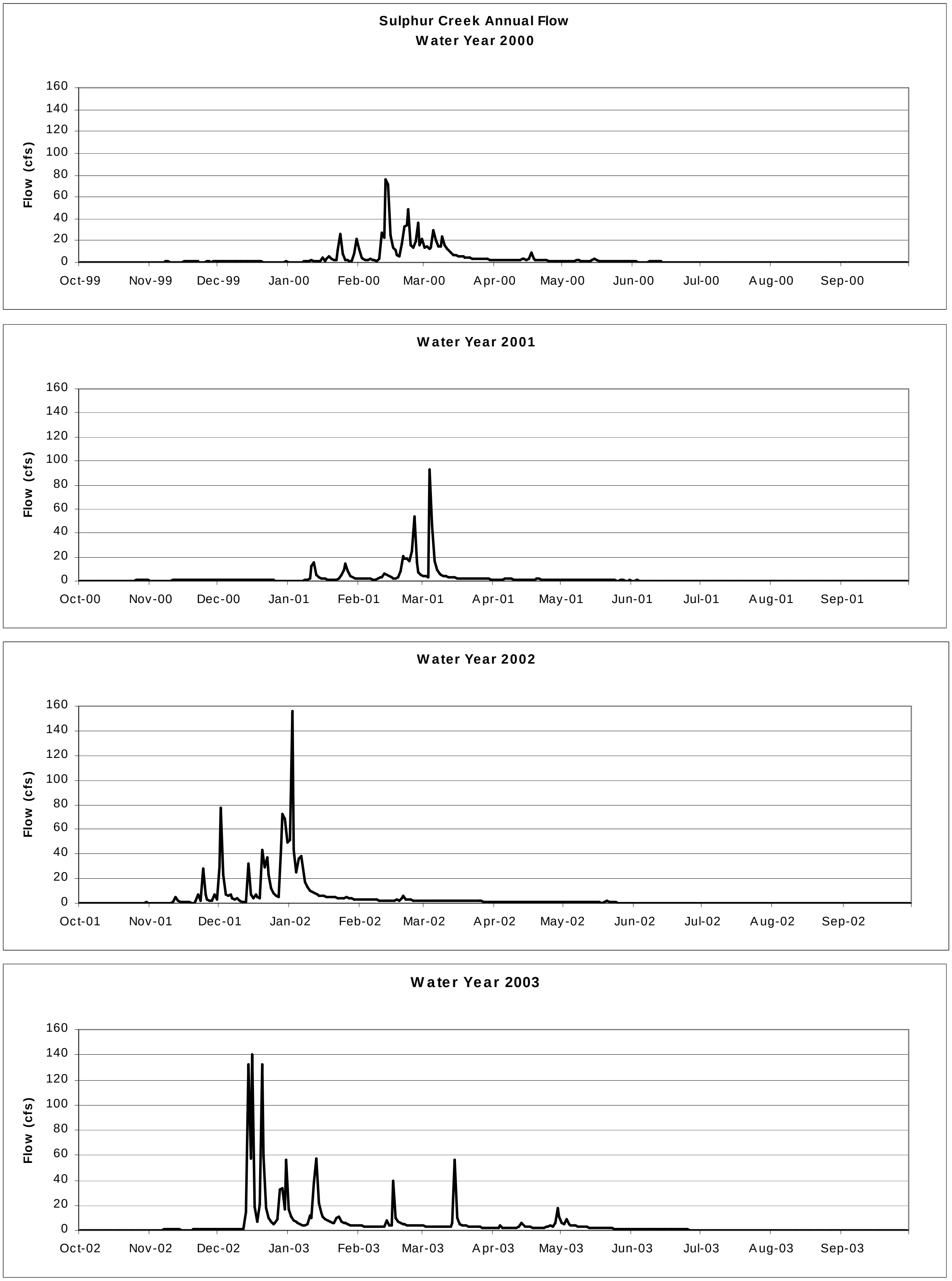

Figure A.1 Daily average flow (cfs) at the USGS stream gauge for four water years.

APPENDIX B. SULPHUR CREEK WATERSHED SAMPLING DATA

Sulphur Creek was sampled six different times during storm events to determine mercury loading patterns throughout the watershed (CVRWQB, unpublished data, Slotton, et al. 2004, Suchanek, et al. 2004). Table B.1 lists total mercury, methylmercury, TSS, and Hg/TSS data collected during these sampling events. The mean total mercury values were used in calculating mercury loads in the Source Analysis section (Table 2.2). Figure B.1 shows sampling points during two storm events where samples were collected at peak flows.

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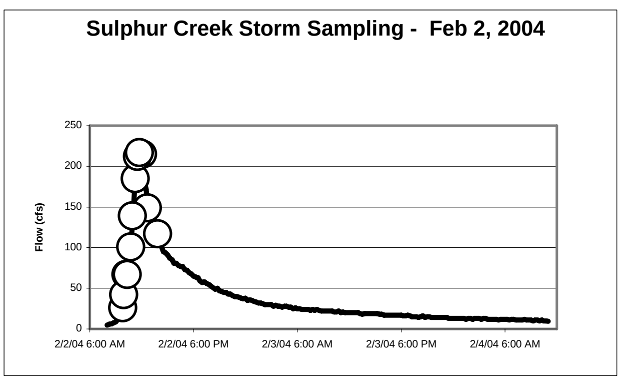
Table B.1 Total Mercury, Methylmercury, TSS and Hg/TSS Data

Total Mercury (ng/L)							
Site (Upstream to Downstream)	**02-14-00**	**02-22-01**	**01/02/02**	**12-14-03**	**02-02-04**	**02-25-04**	**Mean**
SC-20 Upstream Clyde Mine				32	317	128	159
SC-21 Downstream Clyde Mine				76	7229	1466	2924
SC-22 Upstream Elgin Mine				358	21917	3330	8535
SC-23 Downstream Elgin Mine				2506	21878	12629	12338
SC-07 Sulphur Ck u/s West End Mine			987	342	2424	3422	1794
SC-06 Sulphur Ck d/s West End Mine	230	289	806	414	2584	3894	1370
SC-05 Blanck Springs Tributary	1110	2110	635	1949	1308	892	1334
SC-04 Wide Awake Mine Tributary	2450	4300	4950	2727	15243	5376	5841
SC-03 Sulphur Ck d/s Wide Awake & West End	351	374	1340	410	17360	952	3465
SC-09 Empire Mine Tributary		229	137	116	1798	1226	701
SC-08 Sulphur Ck Upstream Wilbur Springs	620	1110	1268	884	12168	6465	3753
SC-01 Sulphur Ck @ USGS Stream Gauge	974	1340	4119	852	12649	3764	3950

Methylmercury (ng/L)							
	02-14-00	**02-22-01**	**01/02/02**	**12-14-03**	**02-02-04**	**02-25-04**	**Mean**
SC-20				0.31		0.31	0.3
SC-21				0.37		0.81	0.6
SC-22				0.57		0.77	0.7
SC-23				0.27		1.2	0.7
SC-07				0.64		0.89	0.8
SC-06		0.50		0.68		1.19	0.8
SC-05				0.40		0.74	0.6
SC-04				1.8		0.75	1.3
SC-03				0.76		1.94	1.4
SC-09				0.45		0.86	0.7
SC-08				0.83		1.63	1.2
SC-01	0.48	0.49		0.17		1.93	0.8

TSS (mg/L)							
	02-14-00	02-22-01	01/02/02	12-14-03	02-02-04	02-25-04	Mean
SC-20				1	229	173	134
SC-21				1.1	242	145	129
SC-22				2.8	100	120	74
SC-23				8	95	118	74
SC-07			349	20	647	1100	529
SC-06		15	367	32	720	1270	481
SC-05		135	3170	68	663	1020	1011
SC-04		26	1100	21	760	1125	606
SC-03		22	440	17	1480	820	556
SC-09			25	3.0	642	540	303
SC-08		43	325	13	550	850	356
SC-01	115	56	396	12	590	618	298

Hg/TSS (mg/kg)							
	02-14-00	02-22-01	01/02/02	12-14-03	02-02-04	02-25-04	Mean
SC-20				32	1.4	0.7	11
SC-21				70	30	10	37
SC-22				130	219	28	126
SC-23				313	229	107	217
SC-07			2.8	17	3.7	3.1	6.7
SC-06		19	2.2	13	3.6	3.1	8.2
SC-05		16	0.2	29	2.0	0.9	9.4
SC-04		165	4.5	130	20	4.8	65
SC-03		17	3.0	24	12	1.2	11
SC-09			5.5	39	2.8	2.3	12
SC-08		26	3.9	66	22	7.6	25
SC-01	8.5	24	10	71	21	6.1	24



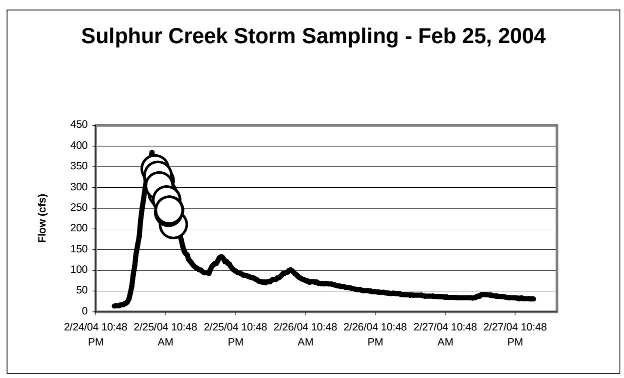


Figure B.1 Watershed wide samples collected in Sulphur Creek during two storm events. White circles indicate samples collected from upstream to downstream during each event.

APPENDIX C. SULPHUR CREEK WATERSHED MERCURY LOAD CALCULATIONS

Mercury loads in the Sulphur Creek watershed were estimated by multiplying the average total mercury concentrations at each site (Table B.1) by estimated flows at each site (Table A.2). Loads are presented in Table C.1. Areas not shaded provide the estimated loads at each of the sampling sites. Areas shaded in gray provide estimated loads from tributaries and sub-watersheds listed in Table 2.2 of the Source Analysis.

Table C.1 Estimated Mercury Loads from Tributaries and Sub-watersheds within the Sulphur Creek Watershed (kg/yr)

Water Year	Upstream Clyde	Clyde Mine Sub-watershed (Freshwater Branch)	Difference Between Upstream and Downstream Clyde Mine	Upstream Elgin	Elgin Mine Sub-watershed (West Branch)	Difference Between Upstream and Downstream Elgin Mine	Upstream West End	Upper Watershed (East Branch, Salt Branch, mainstem Sulphur Ck to Upstream of West End Mine)	Downstream West End	West End Mine Sub-watershed	Wide Awake Mine Tributary	Blanck Springs Tributary	Below Manzanita Mine	Manzanita Mine Sub-watershed	Empire Mine Tributary	Upstream Wilbur Hot Springs	Central Mine Sub-watershed	Wilbur Springs Sub-watershed	USGS Gauge
Site Code	**SC-20**	**SC-21**		**SC-22**	**SC-23**		**SC-07**		**SC-06**		**SC-04**	**SC-05**	**SC-03**		**SC-09**	**SC-08**			**SC-01**
			21-20			**23-22**		**7-(21+23)**		**6-7**				**3-(4+5+6)**			**8-(9+3)**	**1-8**	
2000	0.01	0.38	0.37	1.38	2.47	1.09	3.95	1.10	3.17	-0.78	0.76	0.02	8.39	4.43	0.08	10.23	1.76	0.76	10.98
2001	0.01	0.25	0.24	0.87	1.58	0.71	2.52	0.69	2.02	-0.50	0.49	0.01	5.36	2.83	0.05	6.53	1.12	0.48	7.01
2002	0.02	0.48	0.46	1.74	3.10	1.37	4.97	1.39	3.99	-0.98	0.96	0.03	10.57	5.59	0.10	12.88	2.21	0.95	13.83
2003	0.02	0.56	0.54	2.02	3.62	1.60	5.80	1.61	4.65	-1.15	1.12	0.03	12.31	6.51	0.11	15.00	2.58	1.11	16.11
Avg	0.01	0.42	0.40	1.50	2.69	1.19	4.31	1.20	3.46	-0.85	0.83	0.02	9.16	4.84	0.08	11.16	1.92	0.83	11.98

APPENDIX D. GEOTHERMAL SPRING DATA

Table D.1 provides the raw data for water samples collected at the geothermal springs that flow to Sulphur Creek. Constituents measured at the gauge include total mercury, methylmercury, and TSS.

Table D.1 Data Collected at Sulphur Creek Geothermal Springs

Project Code[a]	Spring	Date	THg (ng/L)	MeHg (ng/L)	TSS (mg/L)	Average Flow (cfs)
Goff2001	Elgin	05/24/94	11,000			0.015
Goff2001	Blanck Hot Spring	05/22/94	6,900			0.008
Goff2001	Jones Fountain of Life	05/23/94	22,000			0.012
CALFED5A	Jones Fountain of Life	02/14/00	24,300			0.012
CALFED5A	Jones Fountain of Life	02/22/01	33,600	20.4	46	0.012
CVRWQCB04	Jones Fountain of Life	02/02/04	26,668		16.93	0.012
CVRWQCB04	Jones Fountain of Life	02/25/04		13.5		0.012
Goff2001	Elbow Hot Spring	05/23/94	61,000			0.0003
CALFED5A	Wilbur Springs	02/22/01	3,460	3.73	5	0.047
CALFED5A	Wilbur Springs	02/22/01	3,970	1.28	12	0.047
Goff2001	Wilbur Springs	05/21/94	6,700			0.047
CALFED5A	Wilbur Springs	02/22/01	7,250	2.01	6	0.047

(a) CALFED5A - Suchanek, et al, 2004
CVRWQCB 04 – Samples collected by Regional Board Staff in 2004
Goff2001 – Goff et al, 2001

APPENDIX E. ATMOSPHERIC DEPOSITION LOAD ESTIMATES

Atmospheric input is the wet and dry deposition falling directly to water surfaces and indirect deposition on the terrestrial watershed with subsequent runoff during storms of a portion of the deposited mercury.

Direct Deposition to Water Surface

Equation E.1 was used to determine an annual direct deposition rate for mercury on surface water in Sulphur Creek:

(E.1) $$Dt = (CwPyA)(1+Kd)$$

Dt = Total annual mercury deposition to Sulphur Creek (kg/yr)
Cw = Concentration of mercury in precipitation (ng/L)
Py = Annual precipitation at Sulphur Creek (0.682 meters/yr)
A = Surface water area of Sulphur Creek (estimate 17200 meters^2)
Kd = Dry deposition coefficient (ratio of dry to wet deposition; assumed to be 1.0)

Direct wet atmospheric loads were calculated using both a lower and an upper estimate of mercury concentrations in rain in California as no information has been collected in Sulphur Creek. The smaller value of 3.9 ng/L in Table E-1 is the average concentration measured in rain between 1998 and 1999 at Covelo, California. Covelo is located about a hundred miles north of San Francisco in the Coast range in Mendocino County. The site is part of the National Mercury Deposition Network (NADP, 2000a,b) and is believed to represent mercury concentrations in air masses blowing on shore off the North Pacific Ocean. The upper value of 8.0 ng/L is the average concentration from three locations in the San Francisco Bay Area between September 1999 and August 2000 (SFEI, 2001).

Dry atmospheric deposition data are not available; therefore it was estimated as a percentage of wet deposition (SFEI, 2001; NADP, 2000a). Dry deposition was calculated assuming it was equal to the wet deposition value (Table E-1).

Direct deposition of mercury on the surface of Sulphur Creek was estimated to be 0.09 to 0.19 g/yr. Direct atmospheric deposition on Sulphur Creek accounts for less than 0.1 percent of the total annual mercury load carried in the water body.

Mine waste, geothermal sources, or disturbed rock that is naturally enriched with mercury from Sulphur Creek may emit mercury to the atmosphere, but this value is not known. Based on measurements of mercury fluxing from soil at 22 locations at the Sulphur Bank Mercury Mine (SBMM) in nearby Clear Lake, Gustin and colleagues estimated an annual flux of 6.5 kg mercury from the mine site (Gustin *et al.*, 2000). The flux estimates were of mercury emitted from the soil; levels of redeposition were not measured. Comparable estimates of the amount of emitted mercury that redeposits in the Sulphur Creek watershed have not been made. Mercury fluxing from the soil may be in the form of elemental mercury, which is relatively stable and can travel long distances in air, or reactive gaseous mercury, which is more likely to be deposited soon after emission (Gustin *et al.*, 2000). Predominant westerly winds may transport mercury to Sulphur Creek from flux at the SBMM in nearby Clear Lake.

Table E.1 Atmospheric Deposition of Mercury to Surface of Sulphur Creek

Wet Deposition Hg Concentration (ng/L) (a,b)		Average Precipitation (m/yr) (c)	Area of Sulphur Creek (m^2)	Annual Wet Hg Deposition (g/yr)
Lower limit wet	3.9	0.682	**17200**	0.046
Upper limit wet	8.0	0.682	**17200**	0.094
Annual Wet Hg Deposition (g/yr)		Dry Deposition Percent of Wet Deposition	Total Annual Hg Deposition Wet and Dry (g/yr)	
Lower limit wet	0.046	100%	0.09	
Upper limit wet	0.094	100%	0.19	

(a) Lower limit of 3.85 ng/L is average wet deposition recorded by the National Mercury Deposition Network at its Covelo, CA station (NADP, 2000a).
(b) Upper limit of 8.0 ng/L is average wet deposition at three stations in San Francisco Bay Area (SFEI, 2001b).
(c) Measured at the Indian Valley Reservoir rain gauge operated by DWR.

Loss of mercury by volatilization from the Sulphur Creek water column to the atmosphere has not been estimated. Elemental mercury (Hg^0) is able to volatilize to the atmosphere. Rate of loss depends upon temperature and concentrations of elemental mercury in the water column and atmosphere. Mercury flux to the atmosphere from Sulphur Creek is considered insignificant particularly since the creek is largely dry for half the year.

Indirect Deposition of Atmospheric Mercury to Watershed and Transport in Runoff

To estimate the amount of mercury from the atmosphere to the watershed that reaches Sulphur Creek, Regional Board staff applied the rates of mercury deposition and average annual precipitation described above to the area of the entire Sulphur Creek watershed. The watershed area of 6543 acres is estimated to receive 70-144 g/year of mercury from the atmosphere. Assuming 10% of the terrestrial load is transported into waterways (Dolan *et al.*, 1993; SFEI, 2000) the indirect atmospheric contribution to loads in Sulphur Creek is 7-14 g/year.

Table E.2. Indirect Atmospheric Deposition of Mercury to Sulphur Creek

Hg in rainfall, ng/L	Surface area of watershed, m2	Annual rainfall, m/year	Wet deposition to watershed area, g/year	Wet Plus Dry Deposition to watershed area (rate of wet = rate of dry), g/yr	Portion of atmospheric Hg deposited to watershed entering creek in runoff	Deposited mercury entering creek in runoff (10% of total atmospheric deposit), g/yr
3.9	26480000	0.682	70	140	0.1	14.0
8.0	26480000	0.682	144	288	0.1	28.8

APPENDIX F. TOTAL MERCURY, METHYLMERCURY, TSS, AND HG/TSS CONCENTRATIONS IN WATER SAMPLES COLLECTED AT THE USGS STREAM GAUGE

Table F.1 provides the raw data for water samples collected at the USGS stream gauge, upstream of the mouth of Sulphur Creek. Constituents measured at the gauge include total mercury, methylmercury, and TSS. Total mercury concentrations and flow were used to develop a regression relationship (Figure F.1) to calculate flow-weighted concentrations to better estimate loads exported to Bear Creek. Total mercury and TSS were also used to develop Hg/TSS ratios for identifying mercury sources. Table F.2 summarizes the data. Data collected using the Sigma Autosampler are not included.

Table F.1 Data Collected at the USGS Stream Gauge

Project Code[a]	Date	THg (ng/L)	MeHg (ng/L)	TSS (mg/L)	Hg/TSS (mg/kg)	Flow (cfs)
CalFED1C	02/27/00	542	0.33			38.1
CalFED1C	03/15/00	528	0.06			7.1
CalFED1C	02/20/01	685	0.492			20.8
CALFED5A	02/22/01	1340	0.489	56	23.9	19
CALFED5B	01/31/00	1560	2.46	49.5	31.5	22
CALFED5B	02/14/00	974	0.48	114.7	8.5	72
CALFED5B	03/02/00	376	0.22	22	17.1	15
CALFED5B	04/17/00	430	0.66	14.1	30.5	9.3
CALFED5B	06/14/00	676	0.76	10.1	66.7	0.5
CALFED5B	08/10/00	690	4.04	59.4	11.6	0.2
CALFED5B	10/11/00	676	1.57	13.9	48.5	0.5
CALFED5B	11/07/00	1320	1.3	4.2	312.1	0.41
CALFED5B	01/11/01	3070	0.92	55.5	55.3	6.3
CALFED5B	02/13/01	906	0.41	7.8	116.3	5
CALFED5B	05/03/01	557	0.15	10.1	55.3	0.9
CALFED5B	07/12/01	1180	18.2	88.6	13.3	0.2
CALFED5B	08/23/01	1051	20.6	65.1	16.1	0.2
CVRWQCB	01/26/97	5316		320	16.6	51.7
CVRWQCB	02/02/98	8402		510	16.5	11.9
CVRWQCB	02/16/98	1965		140	14	26.2
CVRWQCB01	11/20/01	1768		4.6	384.3	0.48
CVRWQCB02	01/02/02	4119		396	10.4	233
CVRWQCB03	03/15/03	1137		162.4	7	110.9
CVRWQCB03	12/14/03	852	0.17	12	71	26.1
CVRWQCB03	12/29/03	2097	0.95	151.7	13.8	90
CVRWQCB04	02/02/04	12649		589.5	21.5	117
CVRWQCB04	02/03/04	425	0.28	11.3	37.8	20
CVRWQCB04	02/16/04	16411	2.54	1262	13	155
CVRWQCB04	02/16/04	13148	3.05	1372	9.6	335
CVRWQCB04	02/17/04	8574	1.1	497.5	17.2	191
CVRWQCB04	02/25/04	3764	1.93	617.9	6.1	220
CVRWQCB04	03/24/04	511.0	0.18	6	85.2	5.5
CVRWQCB04	04/30/04	303.0	0.44	18.7	16.2	2.2
CVRWQCB04	06/09/04	245	0.36	6.4	38.2	0.63
Goff2001	05/22/94	1000				

(a) CALFED1C – Domagalski et al. 2004
CALFED5A - Suchanek, et al, 2004
CALFED5B - Slotton, et al, 2004
CVRWQCB – Foe and Croyle, 1998
CVRWQCB 01 – 04 – Samples collected by Regional Board Staff between years 2001 and 2004
Goff2001 – Goff et al, 2001

Table F.2 Summary Data for Water Samples Collected at the USGS Stream Gauge

	THg (ng/L)	MeHg (ng/L)	TSS (mg/L)	Hg/TSS (mg/kg)	Flow (cfs)
Average	2890	2	214	51.1	53.4
Minimum	245	0.1	4	6.1	0.2
Median	1094	1	56	17.2	17
Maximum	16411	21	1372	384	335
Count	34	27	31	31	34

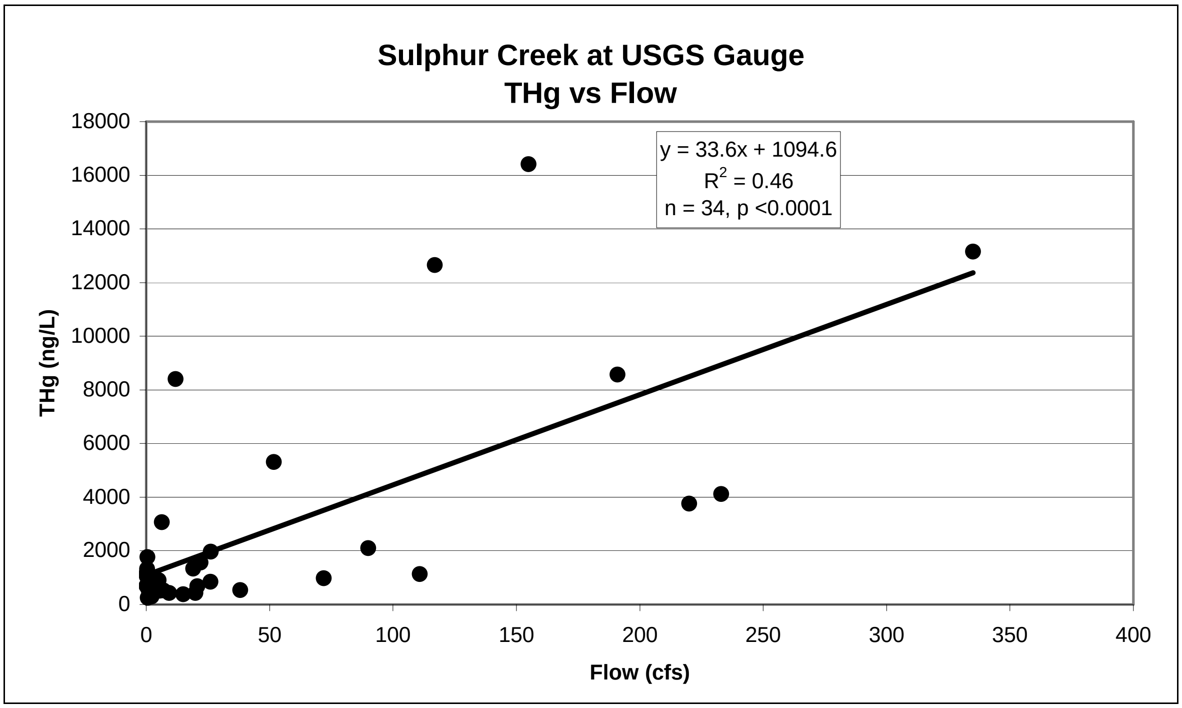


Figure F.1 Mercury concentration and flow relationship at the Sulphur Creek flow gauge

APPENDIX G. SIGMA AUTOSAMPLER DATA

Regional Board Staff set up a Sigma Autosampler at the USGS stream gauge to collect water samples every ninety minutes during the storm event between February 25th and 26th, 2004. The Autosampler was deployed at noon on the 25th and retrieved at noon on the 26th. Samples were collected in 1-Liter plastic bottles in the Autosampler. Regional Board Staff aliquoted a total mercury and TSS sample from each bottle using clean hands techniques. Loads were estimated for each sample using the flow recorded every 15 minutes at the USGS stream gauge. Figures G.1 through G.6 show the relationships of total mercury and TSS to flow.

Table G.1 Sigma Autosampler Data

Sample #	Date	Time	Flow (cfs)	THg (ng/L)	Hg Load (g/hr)	TSS (mg/L)	Hg/TSS (mg/kg)
1	02/25/04	12:00 AM	14	231	0.3	2.75	83.9
2	02/25/04	1:30 AM	14	299	0.4	1.75	170.7
3	02/25/04	3:00 AM	16	368	0.6	14.5	25.4
4	02/25/04	4:30 AM	31	2373	7.5	104.8	22.6
5	02/25/04	6:00 AM	161	8074	133	1305	6.2
6	02/25/04	7:30 AM	316	6925	223	1390	5.0
7	02/25/04	9:00 AM	345	9510	335	1344	7.1
8	02/25/04	10:30 AM	280	4591	131	1081	4.2
9	02/25/04	12:00 PM	220	2337	52	538.9	4.3
10	02/25/04	1:30 PM	175	3036	54	350	8.7
11	02/25/04	3:00 PM	122	1714	21	295	5.8
13	02/25/04	6:00 PM	94	904	8.7	142	6.4
14	02/25/04	7:30 PM	117	2543	30	375	6.8
15	02/25/04	9:00 PM	121	1438	18	284.4	5.1
17	02/26/04	12:00 AM	90	865	7.9	153.1	5.6
19	02/26/04	3:00 AM	73	848	6.3	111	7.6
21	02/26/04	4:30 AM	82	849	7.1	117	7.3
22	02/26/04	6:00 AM	95	797	7.7	173	4.6
24	02/26/04	7:30 AM	78	631	5.0	114.4	5.5
		Min	14	231	0.3	1.8	4.2
		Avg	129	2544	55	416	21
		Max	345	9510	335	1390	171

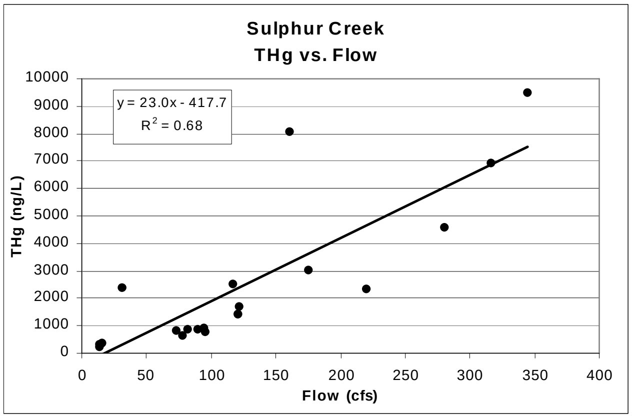


Figure G.1 Total mercury and flow relationship

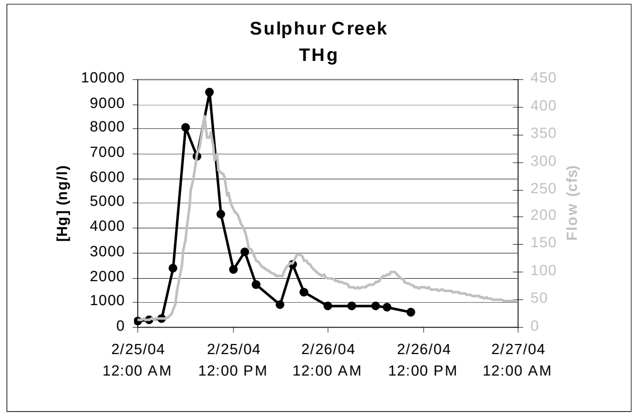


Figure G.2 Total mercury concentrations over time

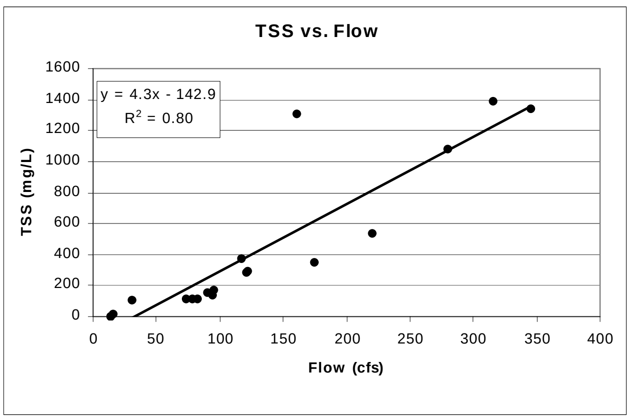


Figure G.3 TSS concentration and flow relationship

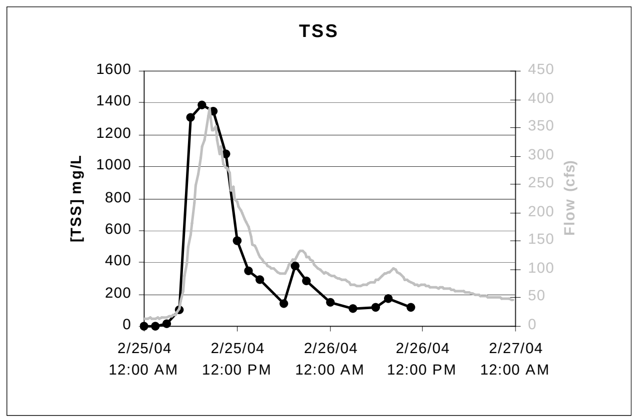


Figure G.4 TSS concentrations over time

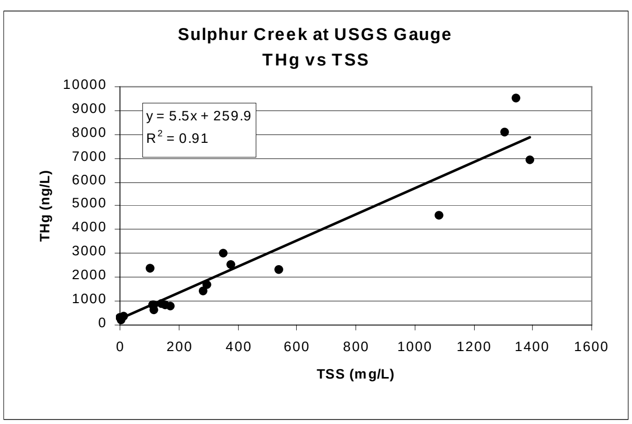


Figure G.5 Autosampler THg and TSS relationship

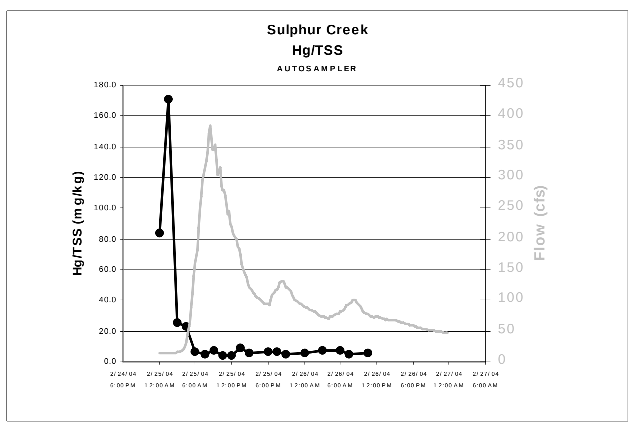


Figure G.6 Hg/TSS concentrations over time